

Automating the Layout of Image for Large, Shared Displays

A thesis submitted in partial fulfilment of the requirements for the Degree of Master of
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Abstract

Advances in display technology are increasing screen size and reducing their costs. Large, wall sized screens can be found in malls, public squares and office buildings displaying photos, videos, advertising, news and announcements. The audience of large displays in public, urban environments can be constantly changing and in this thesis we investigate applying automated layout algorithms to large displays to adapt layouts to changing audiences.

We review current automated layouts, discuss new challenges when applying automated layouts to large screens and present our design space for automated layouts. We investigate the human factors (such as attention, vision, and perception) and the system factors (such as display space and input devices) involved in automated layout for large displays.

This thesis presents the Viewer Aware Layout (VAL) system. VAL is a system that automates the layout of images on a large display and is designed to allow many users to collectively view images. VAL, and features of VAL, are tested for engagement and it is found that there is a significant increase in agreement by users with statements describing an engaging experience when VAL is applied to an image layout. This thesis concludes with a summary of the research contributions and proposes future areas of work.

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1 Introduction

Everyday people in urban environments view an array of images and posters such as product advertisements, news, timetables and announcements. Screens large enough to cover a wall sized area provide new opportunities to display content. Content can be enlarged so that it can be viewed by many users from a distance or content can be placed in an array across a display so that many users can each view individualised content.

Large display layouts can be broken into four categorises. There are static layouts that do not change. There are layouts that change based on pre-programmed, time dependent, scripts [34, 11]. There are user directed layouts which allow users to direct the layout with commands. Users can resize content when their interests change or position content close to where they are standing. But user directed layouts require users to invest time in content layout and invest time in learning layout commands. An alternative is automated layouts [43]. They do not require users to invest time in content layout and they enable content to dynamically adapt to and be influenced by a display's audience.

Consider this example large display layout scenario. A city is hosting a music festival and each act has a promotional poster. A large display is used to present a collection of ten promotional posters. The display has five users, each with different viewing positions and interests (see Figure 1.1). We propose using computer algorithms combined with technology such as human tracking, gesture recognition to automate the positioning, sizing, and movement of images on a large display. Using these technologies and an automated layout algorithm a layout could be found that balances the needs of all users to comfortably view the promotional posters they wish to view.

We consider large displays as wall sized or larger displays that are capable of having many

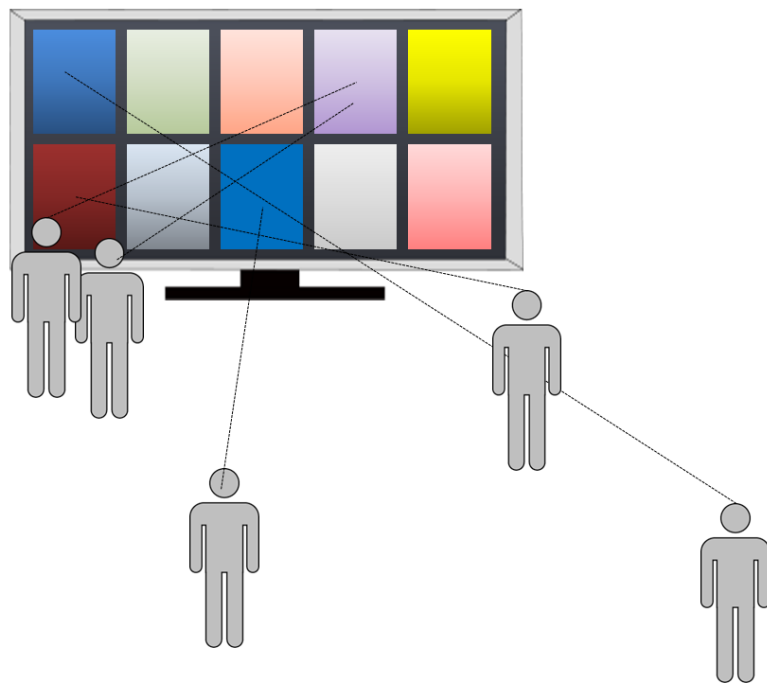


Figure 1.1: An example scenario of five users viewing a large display with an array of images. A line connecting a user to an image indicates that the user is interested in viewing that image.

users and displaying an array of content. We consider automated layouts to be computer directed layouts that automatically adapt to changes in input and do not require a user to direct the placement or size of items on a display. We do not consider the addition or removal of content but instead focus on the layout of images to simplify the research.

Seven chapters follow this introduction. Chapter 2 reviews the literature on large screen displays and automated layouts. The current state of the research into automated layouts for large displays is discussed. Chapter 3 describes our seven goals for automated layouts on large displays. Chapter 4 explores the design factors for hardware used in layout systems. Chapter 5 explores the design factors for layouts and layout transitions. Chapter 6 describes Viewer Aware Layout (VAL), our automated layout system for large, shared displays. Chapter 7 describes the evaluation of VAL. Chapter 8 summarizes the research covered in this thesis.

2 Related Work

This chapter presents the work related to the automated layout of images on large displays. Section 2.1 reviews the science on human perception and the E-conic system that corrects perspective distortion for large displays. It also highlights two variables uniquely important to large display layout, visual angle and perspective distortion. Section 2.2 discusses some of the ways large displays are currently used and the type of content that is displayed on them. Section 2.3 describes automated layout algorithms. It reviews automated layouts used in graph, document and desktop layout. Treemaps, forced based layout, machine learning are some of the different algorithms used in these domains.

The related work dealing with user inputs to a display system is reviewed in Chapter 4 “Hardware Design Factors for Layout Systems”. Chapter 4 reviews display systems that use a variety of ways to detect user interest in content. This chapter describes the background of the topic and work done related to automated layout. Some topics, such as visual angle and perspective distortion, are discussed in more detail later in the thesis.

2.1 Human Perception

When studying image layout we need to consider the capabilities and limitations of the human visual system. Human perception research is the bedrock that is at the beginning of our understanding of a good layout system. It is important to begin here because it defines from what distance and from what angle a human will be able to clearly view and perceive images.

This section highlights two variables, visual angle and perspective distortion. The positioning

and resizing of content will affect both visual angle and perspective distortion, which in turn affects the clarity of content. Because of this affect on the clearness of vision, visual angle and perspective distortion need to be considered for each user when laying content out. These two variables are uniquely important to users of large screens because of the large range of distances and angles a user can view content from.

It seems intuitive that an image to be comfortable viewed on a display should be directly in front of a user and, to put it informally, large in their visual field. With the two variables visual angle and perspective distortion we can measure the benefits to a user when placing content directly in front of them and large in their visual field.

Visual Angle

Visual angle is a key measurement in understanding how content will be perceived on a large screen. Visual angle is a measurement of the size that an image appears on a viewer's retina, usually stated in degrees of arc (see Figure 2.1 on the following page and Equation 2.1). It is an important variable in content layout as it determines the detail a user will be able to perceive in content. The physical size of content or user distance to content do not tell us anything meaningful about a user's perception of content by themselves but both affect visual angle.

$$\tan \frac{B}{2} = \frac{S}{2D} \quad (2.1)$$

Visual Angle: **B** is the visual angle, **S** is the size of the object and **D** is the distance to the

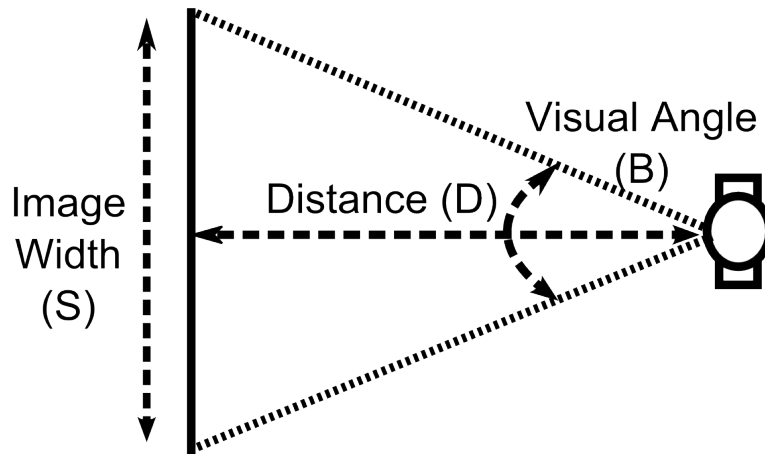


Figure 2.1: Visual angle is a measurement of the size that an image appears on a viewer's retina

Display Type	Distance	Display Width	Horizontal Visual Angle
Mobile Phone	0.53 metres	0.08 metres	9°
Desktop	0.75 metres	0.51 metres	38°
Wall Sized	1.0 metres	5.0 metres	136°
Wall Sized	5.0 metres	5.0 metres	53°
Wall Sized	20.0 metres	5.0 metres	14°

Table 1: Example visual angles of display users

object.

A general rule is that at an arm's length a thumbnail subtends to about 1 degree of visual angle. That is a 1cm object at 60cm has a visual angle of about 1 degree of visual angle. A 5cm newspaper column has a visual angle of 7 degrees when read at a distance of 40cm.

Visual angle indicates various types of visual acuities that play a part in how we see and perceive things. Three important acuities are detection acuity, localisation acuity, and recognition acuity. Detection acuity is the ability to detect stimulus in the visual field and has been approximated as 0.5 seconds of arc [48]. Localisation acuity is the ability to detect if a line

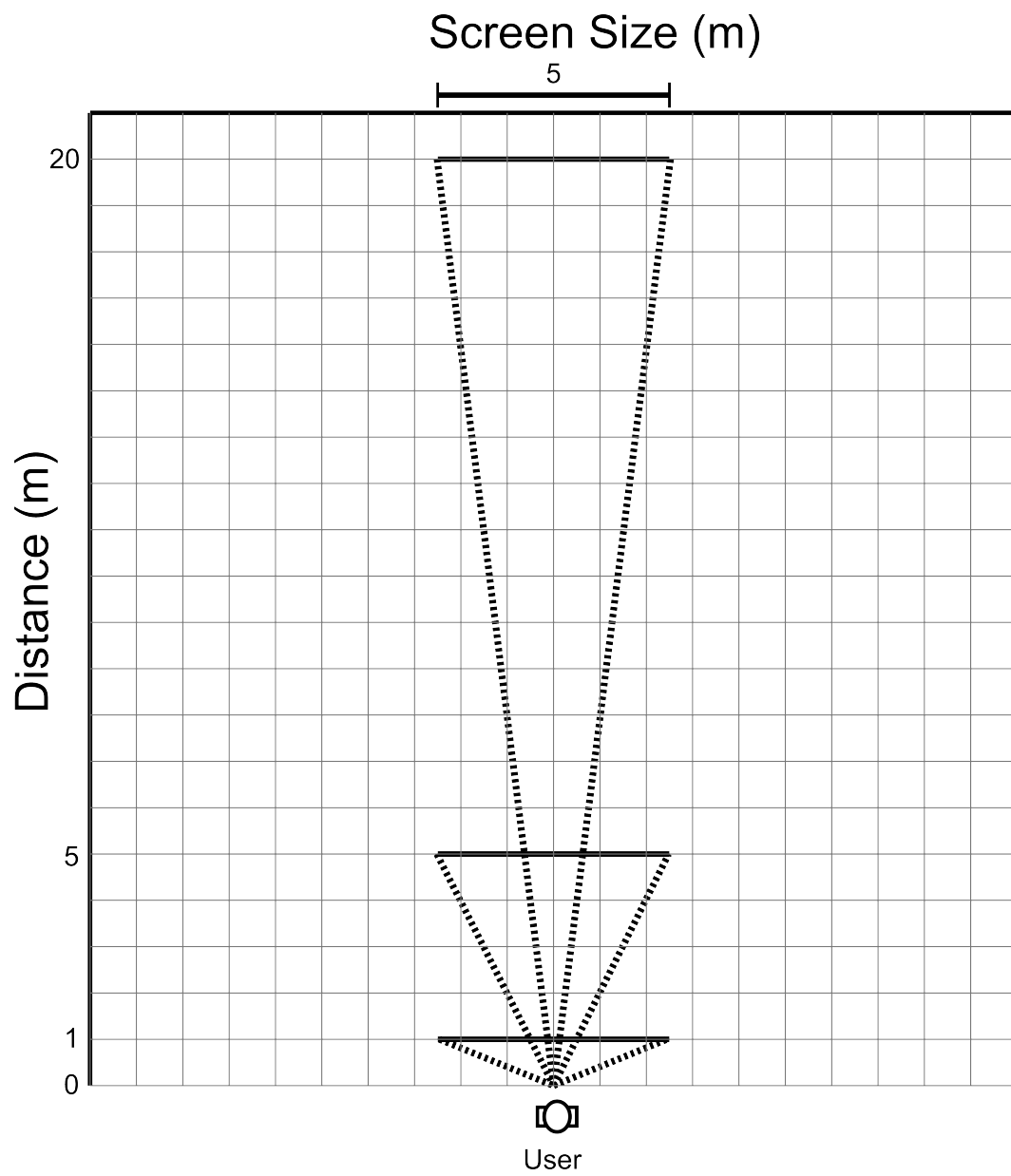


Figure 2.2: The visual angles of a screen at 1, 5 and 20 meters from a user.

is continuous or broken and has been approximated as 2 seconds of arc [63]. And the most relevant to large displays, recognition acuity, which measures readability of letters, is 0.5 minutes of arc [63].

Recognition acuity and readability are mostly consistent at any one visual angle. Chapanis and Scarpa [23] tested the readability of dials at different distances while keeping the visual angle constant. Their experiments found the readability of dials were mostly consistent for a given visual angle (there was a slight, unexplained increase in readability as the distance to the dials increased) when the distance was greater than 28 inches (0.71 metres). Suzuki and Nakata [65] found reaction times in mental rotation tasks to be consistent given a visual angle and a study by Bao et al. [10] demonstrated no difference in participant's ability to identify objects on a large and small display with consistent visual angle. Tan et al. [66] observed user performance in reading being only affected by the visual angle of content, not the location or the physical size of the display it is rendered on. The visual angle of content will indicate a user's ability to perceive detail.

It has been shown that user performance on spatial tasks is greater on large displays than on desktop displays even when the visual angle (retinal size) is held constant [67]. This is a surprising result as the visual acuity (a measure of the clarity of vision) of the images on both screens would be equal if the visual angles are equal and all other factors unchanged. It was suggested by Tan et al. [66] that people use an egocentric strategy when using large displays because of the greater sense of presence. When using an egocentric strategy, a user mentally rotates themselves inside the environment, as opposed to an exocentric strategy where a user will mentally rotate the environment around themselves. An evaluation by Tan et al. [66] provided evidence that people were using an egocentric strategy, and the use of an egocentric strategy by users explains the increased performance in navigation tasks on large displays.

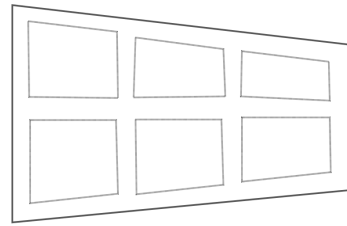


Figure 2.3: This object could be seen as either a trapezoidal window or a rectangular window rotated but it is most commonly perceived as a rectangular window rotated.

Perspective Distortion

The information the brain receives from binocular vision combined with the spatial clues from head movement can still result in ambiguous information about the physical shapes we see. The Trapezoidal Window experiment [3] highlights this ambiguity by providing a viewer with a shape that can be perceived in two mutually exclusive ways.

This experiment involves viewing a trapezoidal window at 6m with both eyes. From this distance the trapezoidal window can be seen as a trapezoidal window or as a rectangular window slanted to the left (Figure 2.3). Most commonly, the window is seen as the simpler shape of a rectangular window slanted to the left. It was hypothesised that this bias in perception was influenced by the past experiences of the viewer.

Allport and Pettigrew [3] tested this hypothesis by performing the Trapezoidal Window experiment on a number of different cultures, some with no windows or common objects with right angles (Zulu people living in rural areas in South Africa) and others from typical urban environments. The rectangular window was still dominantly perceived over the true trapezoidal shape yet the subjects with less exposure to rectangular shapes were less susceptible to the illusion. This bias in perception can be used to a designer's advantage to correct perspective distortion on a display.

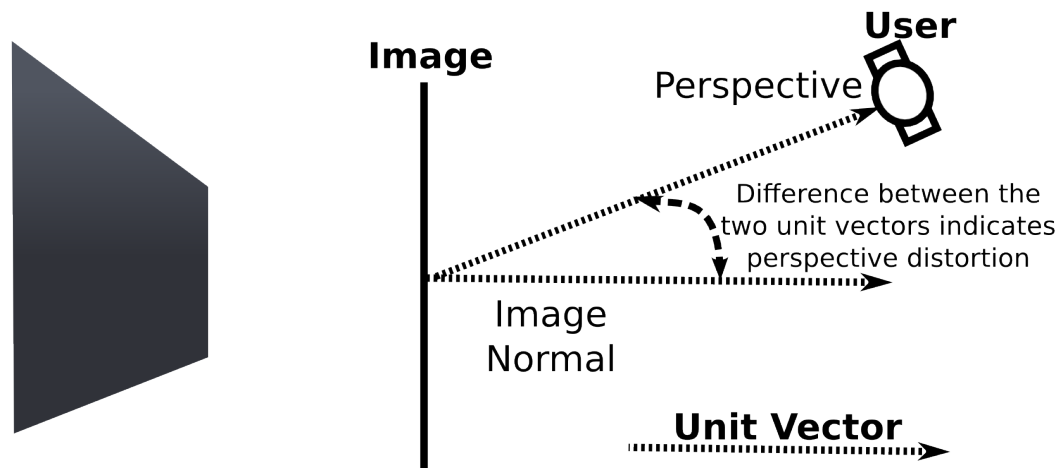


Figure 2.4: (*left*) A rectangular image with perspective distortion (*right*) A user viewing an image at an angle with the image normal and users perspective shown.

Perspective distortion on displays occurs when the direction an image is viewed from is not perpendicular to that image (see Figure 2.4). The perspective distortion of media reduces visual acuity and results in a rectangular image on a display appearing, from the viewer's perspective, as a quadrilateral [50]. Perspective distortion can become a problem on large displays as the relative position between a user and content can vary greatly and this can result in people viewing media from obtuse or acute angles.

However, the perspective distortion of an image can be reduced for a single viewer by rendering the image as a quadrilateral specific to their perspective. From the viewer's perspective, the image appears to have been rotated to face them. The image's true shape is a quadrilateral, but it is perceived by the viewer as a rectangle. This technique is used in sports to draw images on a field as quadrilaterals so that the images will appear rectangular when filmed with a camera from above the field (see Figure 2.5).

E-conic is a system that renders rectangular windows on a display as quadrilaterals so that the perspective distortion is reduced when viewing the display at an angle (see Figure 2.6) [50]. Evaluations performed with this system showed that by reducing perspective distortion



Figure 2.5: Perspective correction of an advertisement on a sports field.



Figure 2.6: Perspective correction being used in the E-conic system.

in this way, user performance can be increased in targeting, reading and pattern-matching.

But such a technique removes perspective distortion for only one viewer. For multiple users the E-conic system finds the neural viewer position for all users (the average of all the viewing vectors) and then renders the content as if it were being viewed from that perspective. The E-conic authors noted that the system's management of multiple users did not scale well beyond four users and that future work would be possible. We outline an optimised technique for reducing perspective distortion for multiple users in the Chapter 5 "Design Factors for Layouts and Layout Transitions".



Figure 2.7: The British Broadcasting Corporation (BBC) has constructed 19 large public displays and aims to maximise viewership for each display.

2.2 Uses of Large Screen Displays

This section describes some current uses of large display of images and looks at what kinds of images are currently been shown on large displays.

Large displays placed in public locations can be used to display many different types of content. They can show content that is relevant to a screen's location like local maps, public announcements and timetables for buses in the area. Huang et al. [34] found large displays being used to display a range of different types of media in central Europe including art, educational content, advertising, fun facts, news and current events. Public screens have been used to show content similar to what people watch on displays in their homes such as movies and sports matches, sometimes remodelled for large audiences [11].

Advertising on large displays in retail stores is increasing [1]. The American retail chain Wal-Mart uses large displays in its stores to display a mix of advertisements and entertainment [1]. Wal-Mart advertising spots, which last for 5 to 15 seconds, are mixed in with entertainment, weather reports and cooking tips to draw people into viewing the display.

Many large displays are placed in public locations with heavy pedestrian traffic to maximise viewership. Locations such as Piccadilly Circus, London and Time Square, New York have some of the largest investments in public displays because of their heavy pedestrian traffic. The British Broadcasting Corporation (BBC) has constructed 19 large public displays and aims to maximise viewership for each display (see Figure 2.7) [11].

Wyche et al. [72] described in detail the uses of large displays in megachurches in America. The authors provide insights into how large displays are being used in megachurches and reported that megachurches have around 2000+ members viewing large displays in their church every week. The authors noted that large displays are one of the most prominent features in many megachurches. Churches use large displays to display a number of different content types including words to hymns, bible verses, administrative announcements, personal messages and videos from members of the congregation.

2.3 Automated Layout Algorithms

The current research into automated layout for large displays is limited in its quantity and scope in comparison to the research for automated layout in other applications. The algorithms that have been used are constrained to adjusting their layout to a single input such as user location or user interest [75, 51]. Methods to weigh multiple inputs still need to be explored.

To gain an understanding of more complex display layouts that consider multiple inputs and factors, we look at automated layouts for window management, document layout and data visualisation. We review these automated layouts because we believe that the techniques used have potential to be generalised to large display layout.

These algorithms vary in their flexibility and computational complexity. The first three layout techniques we review are optimisation techniques, constraints based layouts and force based layouts. These advanced layout methods are capable of taking into account information such as the relationships between content, priority of content, grouping of content and overall layout aesthetics. Then we describe treemaps that are a simpler method for placing content but have been used to place and resize images on a desktop.

Optimisation Techniques

The problem of finding a layout can be approached by defining an optimal layout with an objective function. An objective function of a layout is a function that contains many components which each evaluate a single attribute of a layout. They define, mathematically, an optimal solution as the minimum/maximum of a combination of weighted variables. Describing an objective function lets us define mathematically what makes a good layout.

Lüders et al. [45] used two objective functions to find both optimal layouts (static objective function) and layout transitions (dynamic objective function) for window placement on a desktop computer. The static objective function, an objective for a single layout, measured properties such as how close related content was in a generated layout. The dynamic objective function, an objective for a layout transition, measured properties such as the amount of change in the current layout and the proposed generated layout.

The dynamic objective function was introduced to take into account the costs involved in layout transitions. Changes in item positions were considered a cost because a user would have to remember a new layout and because large changes in a layout may be distracting. Since Lüders et al. method measures the cost of content movements with the dynamic

objective function, an algorithm could weigh the benefits in moving content against the costs involved in changing layouts, and the algorithm only changed layout when the algorithm judges the benefits of a change in layout to outweigh the costs involved in a layout transition.

To find an optimal layout defined with an objective function an iterative algorithm, which searches the solution space to find near optimal or optimal solutions, can be applied. Evolutionary algorithms are one of these iterative algorithms.

Haraty et al. [31] used an evolutionary algorithm to find window layouts in real time. The objective function that measured the suitability of a layout in each evolution, took into account the prominence of important windows, the proximity of related windows to each other and the amount of window overlap. This objective function guided the algorithm in its search for an optimal solution. Other authors have also used evolutionary algorithms for window placement on desktop computers [64, 35, 27].

In an evolutionary algorithm, each proposed solution is evaluated with an objective function. The evolutionary algorithm tests many different solutions to search for the best match. Yet this searching and testing of many solutions has a high computational cost and can restrict their application if the evolutionary algorithm is not responsive to changes in input.

Therefore, the computational complexity of evolutionary algorithms (and other optimisation techniques) must be controlled to be used in real time. Two ways computational complexity can be reduced is by reducing the solution space (either by constraining scope of variables or reducing the number of variables in the objective function) or reducing the cost in calculating variables.

Evolutionary algorithms, and other optimisation techniques, are a powerful tool to solve complex problems. They allow for a mathematical definition of an optimal layout and

optimal layout transition. By mathematically measuring a solution, an algorithm can weigh many variables to judge whether a solution is optimal. But these optimisation techniques can be computationally intensive.

Constraint Based Layouts

Layout can be automated using constraint based layouts. Constraint based layouts use predefined constraints about content to guide the layout process. In other words, constraint based layouts are defined with a set of rules and the satisfactory layouts are the layouts that do not break any of these rules. Constraints can describe such things as the strength of the relationship between content or specify the position of content in relation to other content. For example, a constraint could specify that some text describing a video be placed adjacent to the video that it describes, that a video be aligned with the right side of the screen or that one video be placed above another video. After constraints have been specified a constraint solver is used to find a solution that satisfies all constraints.

Sometimes constraints can contradict each other and different algorithms deal with constraint conflicts in different ways [43]. Constraints can be given a priority so conflicts can be resolved. In the case of two constraints conflicting with the same priority, the conflict can be solved using a first comes first served principle or a constraint grammar can be constructed so as to not allow conflicting constraints to be defined.

Constraint solvers can be combined with other algorithms. One algorithm can perform the placement of content based on some priority and at the same time a constraint solver can restrict the allowable solutions to ones that satisfy all constraints. This is beneficial if there is a property that needs enforcing in a layout like a specific image to always be aligned with

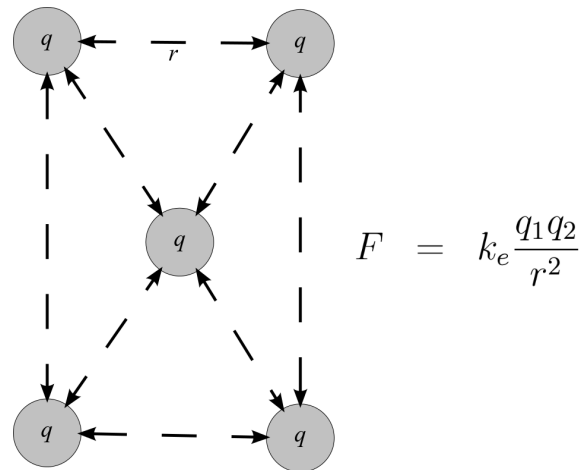


Figure 2.8: Coulomb's Law: \mathbf{F} is the force acting simultaneously on particles with charges \mathbf{q}_1 and \mathbf{q}_2 , \mathbf{r} is the distance between particles and \mathbf{k}_e is called the Coulomb constant.

the top of the screen. Constraints are an optional addition to a layout system that can be used to enforce rules.

Force Based Layouts

Force based layouts simulate the movement of physical objects to find aesthetically pleasing and well spaced layouts. A common method is to simulate charged particles using Coulomb's Law (see Figure 2.8). Coulomb's Law states that charged particles exert forces on each other proportional to the inverse square of the distance between themselves. These forces result in particles quickly being pushed away from each other and tending towards a state where each particle is the farthest possible distances from other particles (a local low energy state). This behaviour results in symmetrical patterns with even spaces. The even spacing and the symmetry made by charged particle arrangements makes them a good candidate for simulation to produce aesthetically pleasing and well spaced layouts.

Another advantage with force directed layouts is that they are iterative, and in each iteration objects move an incremental distances to the next layout. These successions of small movements

towards a destination position allows a graphical representation of objects transitioning from one layout to another and the movements are modelled on real world forces that are natural and familiar to people.

$$pV = k \quad (2.2)$$

Boyle's law: **p** is the pressure of the gas, **V** is the volume of the gas and **k** is a constant of the system

Ali et al. [2] used a combination of constraint based and forced based layout mechanisms to place items on interactive documents (see Figure 2.9 on the next page). In addition to using repulsion and attraction forces, the authors used Boyle's Law (see Equation 2.2) to produce a force to maximise space usage. Items expanded with pressure proportional to the amount of unused space so that items expanded most forcefully when there was large unused space in a document.

Lüders et al. [45] used force based layout for desktop content placement (as well as an optimisation technique in the pre-processing phase as described earlier). Their layout process was broken into two phases, a global layout phase and a post-processing phase. In the global layout phase, items were placed in a grid, all as the same size. The item's placement in the grid was determined using the simulated annealing algorithm [57]. In the post-processing phase, a force based layout was used that made incremental changes to the layout.

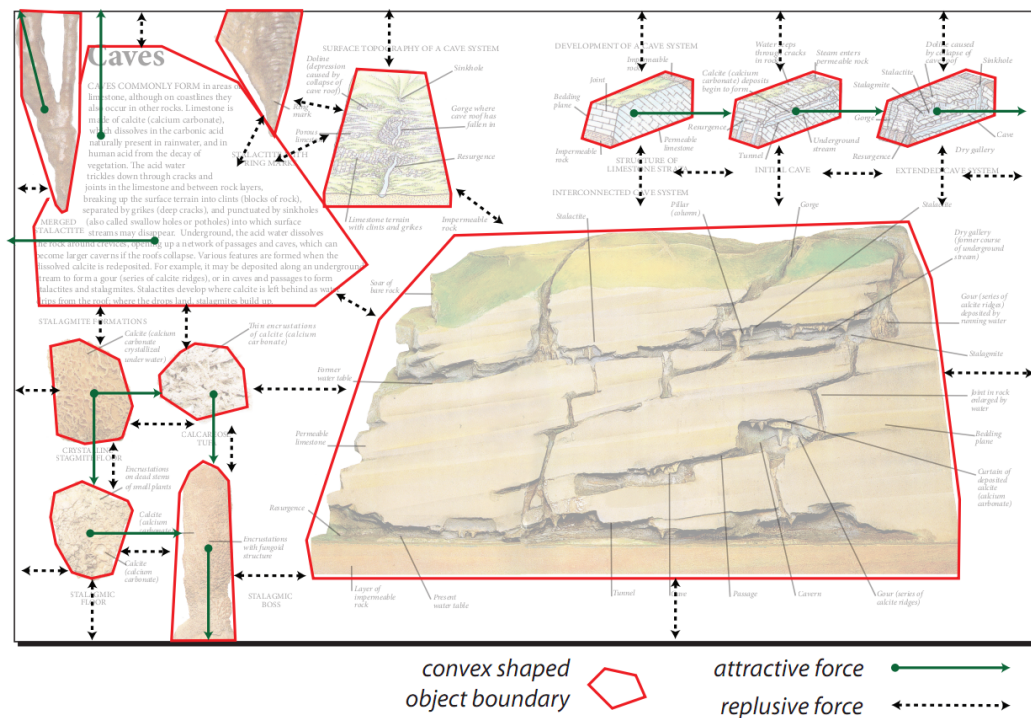


Figure 2.9: Forced based document layout. Items on the document exert forces on each other.

Treemaps

Treemaps are a data visualisation method that can be used to divide rectangular areas into a given number of areas. The sizes of the divisions are based on a list of weights for each area. Treemaps are stored in a tree, a hierarchical data structure. The interior nodes correspond to either a horizontal or vertical division and the terminal nodes correspond to rectangles.

Many treemap algorithms create rectangles with many different aspect ratios and this does not suit the placement of media that have fixed aspect ratios like videos and photos. Although, some treemap algorithms are designed to make rectangular areas that have a more consistent aspect ratio [18]. Another difficulty with using treemaps for content placement is that some treemap algorithms do not keep objects in consistent locations when updated. An adjustment in one item's size could cause an algorithm to relocate it to another area of the screen which



Figure 2.10: Treemap layout of images

would not be ideal for a user viewing media.

Kustanowitz and Shneiderman [41] developed a system that automates the layout of photos for a desktop display using a treemap algorithm. A desktop window was first divided into rectangular regions for each category of photos, and within those regions were laid out, in a grid, the photos they contained (see Figure 2.10). An algorithm called BRQ-Layout controlled the way the application window was divided into rectangles, based on the weights of each section. The system was capable of dynamically adding and removing photos.

Atkins [6] developed a system that automates the layout also of photos for a desktop display using a treemap algorithm. As photos were pushed to the treemap, the algorithm would test the placement of a photo at each possible node to find the best match. The suitability of a placement was determined by a metric, calculated using the aspect ratios and the areas of each photo. A limitation of this implementation was that the layouts created depend on the order that photos were pushed to the algorithm. It also did not support the resizing or moving of photos.

2.4 Conclusion

In our discussion on human perception, we highlighted two important variables, visual angle and perspective distortion, which both affect the clearness of vision of images on large displays. It is important to consider visual angle and perspective distortion when laying content out on large displays as the distance and angle viewers are standing relative to the display can vary greatly.

In our discussion on automated layouts, we looked at research into automated graph, document and desktop layout. Force based layouts have been used to produce balanced and aesthetically pleasing document and desktop layouts. Researchers have published optimisations and improvements for force based layouts. Additionally, constraints and optimisation techniques have been used for document and desktop layouts.

These discoveries in graph, document and desktop layout could be ported to large displays. There are similarities between the layout of windows on a desktop or the placement of media on a document and the automated layout of information on a large display. Both require a layout system to weigh many variables when searching for a solution, fill space on a display and to be aesthetically pleasing. Large displays may benefit from the well spaced, symmetric layouts produced by force based algorithms. They may also benefit from simulations from the domain of document layout, such as Boyle's Law which produces space filling layouts.

Yet large, shared displays have layout problems that are unique. Large displays have multiple users that may be scattered around the display, some close to the display and some far away. These users may not be stationary and will be free to move around in front of the large area of a big display. Large displays have a larger surface to place items on and the display allows for more than one user to view content. These are new challengers for automated layout and

researchers are only beginning to explore solutions for them.

3 Goals for Automated Layouts

Automation frees a user's time and cognitive resources from a task [?]. With an automated layout system there is no requirement to move or resize items, no need for users to collaborate to come to a consensus on a layout and no need to learn commands for positioning images on a display. By automating the layout, users will be freed from investing their time or cognitive resources in managing the layout.

We see automated layouts as being especially suited for deployment in public locations where users may only be willing to invest a limited amount of time in interacting with the display [17]. Pedestrians may weigh the investment of time required to utilise the display against the perceived benefit of using the display. Therefore, by reducing the investment of time required to interact with a display we may increase display utilisation.

We construct six design goals for a large display layout system in a public location. First, the system will provide an engaging user experience. Second, the system will be inclusive of all interested users. Third, the system will tailor its layouts to users' interests and viewing positions. Fourth, the system will resolve conflicting interests over screen space between viewers. Fifth, the system will be content agnostic. Sixth, the system will utilise lightweight interaction.

Engaging user experience Huang et al. [34], after performing a field study on the current uses of large displays in four European cities, reported users not spending a lot of time interacting with public displays. The authors noted that public displays are often assumed to be eye catching but that attention and engagement were dependent on many factors. For example, the authors observed the majority of people approaching a display not because

they were attracted to the display itself but because nearby objects caught their attention. One person being observed approached a computer display to view a product adjacent to the computer display and only after viewing the product did they turn their attention to the computer display. This, and other observations, by the authors led them to suggest that the attractiveness of large displays cannot be assumed and that many current deployments are not eye-catching.

It is our goal to create an engaging user experience. Engagement will be important for large display systems deployed in public locations where advertising, promotions and products will be competing for viewer's attention. The producers of images for public display such as advertisers have an interest in maximising the number of viewers of these images and having users engaged in their viewing of images. Pedestrians also have an interest in viewing public images that they find engaging.

Bannon [9] saw the need for interfaces to be engaging to excite, motivate and enhance the user experience. O'Brien and Toms [55] argued that engagement is important in software design because users decide to invest their money, time, and effort into systems not only because of their utility, usability or efficiency but because the software also offers an engaging and emotional experience and derived six distinct attributes of engagement (perceived usability, aesthetics, focused attention, felt involvement, novelty, and endurability). The six attributes were evaluated for reliability and validity with two large scale online tests. We will use these six attributes as a guideline for producing engaging systems.

Inclusive of users Frequently in urban environments there are images, digital or print, on public display showing information about products, announcements, movies or festivals. The providers of these images have a commercial interest in showing them to a large number of

pedestrians so displays are placed in locations of heavy pedestrian traffic [11].

But limitations in the interaction methods or the system can prevent a large number of users for being included in a system's decisions. For example, if the system requires all users to input commands via a touch screen then users must wait their turn to be next to the screen. We see automated layouts being inclusive of users regardless of their distance to the display or however many people there are using the display. This will require an interaction method that can be scaled to many users and a system that can consider the interests of many users.

Layout tailored to user interests and viewing positions The ultimate appearance of content for each user will be dependent on that user's perspective. The angle that users view content from will affect the amount of perspective distortion for that user. The distance content is viewed at by users will affect the visual angle of that content — visual angle is a measurement of the size that an image will appear on the viewer's retina. Moving the position of content on the screen will change the image perceived for each viewer in different ways. To intelligently adapt the layout of content for viewers of a large screen we aim to design systems that will tailor the layout to users' interests and viewing positions.

Resolve conflicts of interest over the use of screen space CityWall, a large public display with heavy pedestrian traffic, often had multiple users viewing and using the display [58]. But the researchers who installed the display often observed conflicts in interest over the usage of display space. If an automated layout is to tailor the layout to users' interests and viewing positions then it will also need to manage the limited space on the display with automated solutions so that conflicting interests are resolved.

Content agnostic We aim to produce layout solutions that are content agnostic. A system can be applied to a broader range of image collections if it is not dependent on being given data describing images. We aim to design a layout system that will be dependent on user inputs and the displays environment instead of any data that describes the images.

Lightweight interaction method Brignull and Rogers [17], after observing users of their Opinionizer system, recommended that the form of interaction with public displays should be “very lightweight” as requiring a large investment of time can deter people from using the display. We see system benefitting from interaction methods that are intuitive and quick to learn.

The interaction styles and user commands differ between manual and automatic layouts. In a manual layout the commands are direct manipulations of image sizes or image positions. There are commands to aid layout such as showing an overview of the display, or commands to aid collaboration between users to come to a consensus on a layout [38]. On the other hand, commands to automated layouts are abstracted and simplified from their actions such as expressions of interest.

For example, a user of a display may need to tell a manual layout system that they need an image positioned in front of themselves and they must also command the system to enlarge the image because they are at a distance. These are two different commands which both require direct manipulation of a variable. In contrast, the command to an automated layout system could be abstracted to an expression of interest. The user tells the system that they are interested in an image and the system moves and resizes the image on the display with that knowledge in mind. Because of this abstraction the command set is simplified.

The advantage of automated layouts over manual layouts are their abstracted and simplified

command set combined with their automation and these advantages reduce the investment of time required in layout and layout commands. Automated layouts do not require an investment in layout and this makes them suitable to be applied in situations where users' time is limited or users' cognitive focus needs to be freed from the task of content layout.

But user input methods could add an investment of time if they are complex or unintuitive. Lightweight input methods, which require little investment of time, will parallel the lack of investment required in layout and support the advantages of automated layouts.

4 Hardware Design Factors for Layout Systems

This chapter explores the hardware for a layout system and is divided into two sections. The screen section covers the possible sizes, environments and technologies of a display screen. The user section considers hardware that could be used to gather information about users such as user position, user gestures and body posture.

4.1 Screen Properties

This section outlines the screen properties that influence the capabilities and limitations of a layout algorithm, such as size, resolution, colour limitations and environment of a screen.

Display Type

Three frequently used methods to produce large displays are with a projector, projectors tiled together, or an array of liquid crystal display (LCD) screens tilted together to form one large display (but with noticeable gaps between them) [52].

Some large computer displays have viewing restrictions and limitations in the colours they can reproduce. Viewing a LCD at an angle can change the colour seen and reduce the intensity of the light being projected at the user [71]. The contrast between colours on projected images can be reduced if the environment they are in is too bright [52].

Display space is valuable and the amount of information that can be shown to a user is limited. This section discusses screen resolution and screen size (height and width in metres). The resolution of the screen limits the detail that can be displays to close viewers. And the

Display Type	Horizontal Visual Angle	Horizontal Resolution	Pixels per degree of visual angle
Mobile Phone	9°	400 pixels	44.4
Desktop	38°	1680 pixels	44.2
Wall Sized	136°	6144 pixels	45.1
Wall Sized	53°	6144 pixels	115.9
Wall Sized	14°	6144 pixels	438.9

Table 2: Pixels per degree of computer displays users

screen size limits the detail that can be displayed to far viewers.

The visual acuity of an image on the screen is limited by the display size for far users. Content can be increased in size to increase the visual angle of that content, and consequently the visual acuity of that content, but this technique will be limited by the display size.

The visual acuity of an image on the screen is limited by the screen resolution for close users [74]. Using standardised methods of measuring visual acuity, visual acuity has been shown to be inversely proportional to pixel density [20]. As a user approaches a display there will become a stage where the number of pixels a display can show over a user's visual field is too low and the quality of the image will be lessened and visual acuity decreased.

There is a limit to the amount of detail the human eye can perceive. The human eye has about 180 receptors per degree of visual angle [70]. Ware [70] suggested that 150 pixels per degree is near the limit of a human's ability to perceive detail. Although, Ware noted that this does not take into account aliasing, grey levels and super-acuities.

For an example of pixels per degree consider this example desktop user. The desktop user has a screen resolution of 1680 by 1050 pixels. [they are sitting 0.75 metre from the screen and the screen is 0.51 metres wide. Using Equation 2.1 on page 5:

$$\tan \frac{B}{2} = \frac{S}{2D}$$

$$B = 2 * \arctan \frac{0.5}{2 * 1}$$

$$B = 0.6555 * \frac{180}{\pi}$$

that is a visual angle of 38 degrees. With 1680 pixels horizontally, that is 44.2 pixels per degree. It is clear that this is well below the estimated limits of human vision of 180 receptors per degree.

Consider another example of a user of a large display. The large display has a resolution of 6144 by 1080 pixels. The example user is 20 metres from a 5 metre display, which is a visual angle of 14 degrees (see Table 2 on the previous page), that is 439 pixels per degree. This density of pixels is likely to be greater than the ability of the human eye to perceive the pixels and the display's resolution is no longer a limiting factor. In conclusion, the screen size and resolution will place constraints on the size and number of images that can be shown to users.

Viewing Environment

The environment of a display may influence what are optimal layouts. Some environmental factors that could influence layout are the area that is available to view the display from, the position users will be positioned relative to the display or the restrictions on access to the display.

A likely scenario for many large displays is for them to be flat on a wall and the users to be at the screen height. A variation to this scenario is the users are all on one plane but the display is raised so that close users do not obscure far users' views.

If a display is enclosed in a room then this can restrict the number of users or the distances and angles users can view the display. The number of likely users could be restricted by the size of the room the display is contained in or the number of people that have access to the display. The size of a room a display is in could restrict the positions a user could be positioned relative to the display.

Information describing a display's position relative to users may not be needed if user positions can be gathered. If user positions are known then important information such as users' perspective and if users are obscuring other user's view can be derived.

Information about a displays environment can describe how other variables will be restricted, such as user positions being constrained to an area or the number of users being restricted by the accessibility of a display.

4.2 Lightweight Interaction Methods

The user interaction with automated layouts differs from interaction with other layout systems. There are no commands to directly manipulate the position or size of content, and sometimes the commands are separated or abstracted from their actions.

Large displays present a large physical space for interaction. Users are free to move around this large space and can view the display from a distance. We aim to make an automated layout with an inclusive user experience even of users at a distance therefore they will need to be able to interact from a range of locations. This needs to be considered when reviewing possible interaction methods.

Automated layouts in other domains such as window and document management have mature, standardised way for the user to input information using a mouse and keyboard while on a large display there is a greater range of hardware being proposed for interaction. We review the range of interaction methods that have been previously developed for large display that could be used to determine user interest in images on a large shared display.

It is our goal to tailor the layout to user position and interests. Understanding which user is interested in what content will be important when deciding where to position content. There are a number of technologies that would be capable of enabling users to indicate interest in content with different trade-offs (laser pointers, hand gestures, etc.) and we will discuss how this could best be achieved. A system with the knowledge of what users are interested in can then tailor the layout for each user based on their expressed interests and viewing position.

User Location

Our goal for automated layout systems was to have the system adapt layout to user location. User location determines the parts of the screen a user can comfortably view and this makes it an important input in a layout system. User tracking can be achieved using computer vision techniques. Automated layouts with user tracking have been successfully deployed [49, 75]. OpenCV, an open source software library, enables the tracking of people and their faces from the frames of a video camera [16]. Distances to faces from the camera can be estimated using the size of the face in the video frame, or multiple cameras can be used to triangulate positions of people detected in video frames [26].

Freehand Pointing and Pointing Devices

Pointing could be used to express interest in content. Researchers have made use of laser pointers and freehand pointing as a means for users to indicate items of interest on displays [69, 56]. Aiming a device at content and pressing a button could express interest in targeted content and a second press of the same button could remove interest. Fitts' Law models pointing time and describes a logarithmically relationship between distance to target and pointing time, and also a logarithmically relationship between target size and pointing time (see Figure 4.1 on the following page). Fitts' Law suggests that the time required to move to a target item is small when targets are large (as many items on a large display are) and the large distance between items results in pointing time increasing only logarithmically.

Pointing can be inaccurate if it is hard to spatially calculate the line from a finger/device to the display or if a user cannot hold their hand steady while outstretched [24]. Providing a marker of where a user is pointing will provide feedback of a device's orientation to a user.

$$T = a + b \log_2 \left(1 + \frac{D}{W} \right)$$

Figure 4.1: Fitts' Law: **a** and **b** are constants specific to the pointing device. **W** is the width of the target measured along the axis of motion. **D** is the distance from the starting point to the centre of the target. **T** is the average time taken to complete the movement.

Yet on a shared display markers of device orientations may be distracting to other viewers.

Cheng et al. [24] have proposed a user input method where the user holds their finger between their face and the display and indicate a point of input by lining up their finger tip, from their perspective, with the content of interest, so that their finger lies under the point of interest. This interaction style does not require markers on the display for orientation. It is required that the system detects the location of the user's finger tip and their perspective for this input method. The perspective is taken as a point between a user's two eyes.

Jota et al. [36] compared the performance of users while using a grabbing gesture, pointing gesture and a mouse in solving a puzzle over three distances close, middle and far while the display size was constant. The grabbing gesture was designed to mimic the moment used when someone reaches for a book on a shelf. Participants performed the fastest using the pointing metaphor over all three visual angles, although the results were not conclusive ($p=0.09$). Participants favoured the point as their metaphor of choice when rating the techniques in a survey after the experiment.

Personal Devices

It is common for people to carry mobile phones, which come with many sensors such as accelerometers, near field sensors, magnetometers and cameras. These technologies could

be used to communicate interest in images on a display. For example, optical flow analysis of the video feed or a built in accelerometer can be used to determine the movement of a personal device. Then gestures can be deduced from movement data of the personal device [7].

People could also express interest in content by sending text messages to a display system with their personal device. People are likely to already know how to use their own personal device so it would not be required for them to learn any new device. Sending text messages may require more time for viewers to communicate with the system and this would not be as fluid a way to interact as other techniques like pointing.

Body Posture

Kuno et al. [40] discussed user interaction techniques where the user does not give the computer direct commands but instead the computer reads the user's actions, body language and unconscious movements for intentions and interests. Similarly, Nakanishi et al. [51] used head orientation to change the layout of a number of sub-windows. The sub-window the user was looking at would increase in size while the user's head was orientated towards it.

Ashdown et al. [5] also used head orientation to place a mouse pointer on multiple displays but in a desktop setting. The authors evaluated a technique where the mouse pointer would be placed on the screen that the user's head was orientated towards. The evaluation by the authors found this method reduced the amount of mouse movements required in completing a set of tasks on a desktop computer when compared to the mouse movements required while using stitched screens (as is used in Windows XP).

Bolt et al. [15] created a system where a user's gaze was used to change the way information flowed to its user. The system was in an office like room with one wall covered in a number of displays. The displays contained a range of video feeds and information so a user would have a large number of information feeds available to view. The system used gaze direction to change the content that was being displayed to the user.

Other Methods

Ning et al. [53] proposed six different ways for users to express interest in content (pointing, slapping hand gesture, body gesture, foot button and touch). The six techniques were designed for users passing by a large display with little time to invest in the display.

Yin and Davis [73] produced technology that can count the number of digits someone is holding up to a camera. This technology could be suited to indication interests to a system. A system could mark content from 1 to 5 for one handed commands or 1 to 10 for two handed commands. Also, holding up digits is a gesture that does not require a user to have any electronic equipment on them, reducing the complexity and cost of a system's setup.

Touch input is limited to users close to the screen which removes it as a candidate for a universal indication method for interest. It would be possible to enable users close to the screen to input interest with touch but this would require additional commands to be available for users farther from the screen. Touching also obscures content for other users and can mark the surface of a display.

Speech recognition could be used to allow users to express their interests in items on a display without any hand gestures or hand held equipment [14]. It may be more difficult to detect voice command for a public large display system if it is in a loud environment.

Audiences often clap, cheer and holler when watching sporting events or other events where loud sounds are culturally acceptable. This can also be true of audiences watching similar content on public displays. These audible actions may be expressing enthusiasm, agreement or support and a system that can understand these expressions may be able to make use of them to build a model of its audience. Beusekon et al. suggested that clapping, cheering and waving could be measured by a computer to calculate an audience's support for an athlete or team in competitive sports [68, 21], and this idea could be extended to viewers of displays . When media is displayed that is liked by users, user could audibly express their support and a display system could use this information prioritise the display of popular media.

4.3 Conclusion

This chapter covered hardware for large display layouts. The screen section shows how the screen size can limit the visual acuity of images for far users and how the screen resolution can limit the visual acuity of images for close users. The user section highlights the factors that separate large display interaction methods from other interaction methods. Users are able to utilise a large display from a large area and user commands to an automated layout are unique in that they are often simplified, abstracted commands to a system and not direct manipulations of objects on a display. Possible interaction methods for automated layouts were also reviewed.

5 Design Factors for Layouts and Layout Transitions

The placement of images on large displays is less constrained than on smaller displays. Images can be placed high above users or far to the side of them. There are fewer constraints on the size of images. Images can be enlarged so that it can be seen by viewers far away or an array of content can be shown at smaller sizes. Different images sizes, positions and layout transitions can create layouts with unique aesthetics, moods and characters. We investigate how the three factors size of content, position of content and movement of content, which can all be controlled by a layout system, influence users with the goal of creating an engaging user experience.

This chapter is broken into four parts. First, we discuss techniques to adapt images to user position and consider factors involved in positioning and sizing images for a single user. Second, we expand on the problem of layout for a single user and consider factors involved in image layout for multiple users of a large display. Third, we look at layout transitions, layout responsiveness and animation for when layouts needs to be updated as a result of changes in the display's audience. Fourth, we consider techniques to manage the layout of images as a whole, such as the grid method and distortion techniques.

5.1 Content Size and Position for Individuals

Large displays can support users from a distance of a few metres away up to twenty or more metres. This range of distances means users will have a large range of visual angles of the display. Users can be located on one end of a large display and looking at content next to them or at content on the other end of the display resulting in a large range of perspective distortion. The range of location users can be in relation to a large display has a large effect

on the way a user perceives content. In this section we consider users' perspective of content in the design of automatic layout systems including optimal visual angle, fixed visual angle and perspective correction of images.

Visual angle is the term for the angle an image subtends to (see Figure 2.1) and we use the term *viewer* angle to indicate the angle between the normal of a image on a display and the angle to the viewer (see Figure 2.4).

Content Adaptation to User Position

This subsection examines content adaptation to a user's visual angle so content can be displayed at a range of sizes and for different viewer distances. Content adaptation to visual angle can be used to enhance content's utility on a large display by extending the range of visual angles content can be shown at.

Assumptions must be made about the visual angle of images for desktop or hand held displays because the user distance and sometimes the ultimate size of content is not known when images size is dependent on the varying device screen size. Lacking this information, content designers must produce content that can be viewed at the range of visual angles they assume content will be viewed at. Mobile-phone interfaces have large text and bold buttons relative to the screen size because it is assumed that the visual angle a 10 centimetre screen subtends to is small. Desktop applications have smaller fonts and buttons as the displays are larger.

In contrast, a display system that detects the position of users enables greater precision in the design of content. Text can be sized precisely so that it does not take up more space than is required yet still be displayed at a comfortable size. Images can be sized to be comfortably

viewed based on the user distance.

Semantic zooming is changing the size and detail of objects as the area available to display the object changes [59]. The size an object appears to a user does not only depend on the screen space used to display an object but also the distance to the screen. A number of systems have included semantic zooming based on user distance to the display [8, 37, 38, 32] but do not explicitly base semantic zooming on visual angle.

Visual angle affects the amount of detail visible to the human eye and will determine how large the image will appear in a user's visual field [63]. Using semantic zooming, the amount of information displayed could be increased or decreased as visual angles change. For example, a map could be detailed when the visual angle is large and the map's detail comfortably perceived. A map could be a simple rendering of text reading "map" when the visual angle is small (see Figure 5.1 on the next page). This would enable a user to gather information about content even when the visual angle is small and allow users to be provided with greater detail when the visual angle is large.

Although, viewers may vary in their distance to the screen at a single time. A display may have viewers close to the screen who would benefit if content is rendered in detail and have viewers far from the screen that will not be able to perceive this detail. This needs to be taken into consideration when adapting content to visual angle. An image could be displayed that contains both low and high detail by having an image within a larger image, such as having a translucent text of a map over a detailed map (see Figure 5.2). The translucent text can be displayed when the system detects a far user, and because the text is translucent the close user will still be able to view the detailed map.

Another property of content to consider when it is viewed at different visual angles is whether

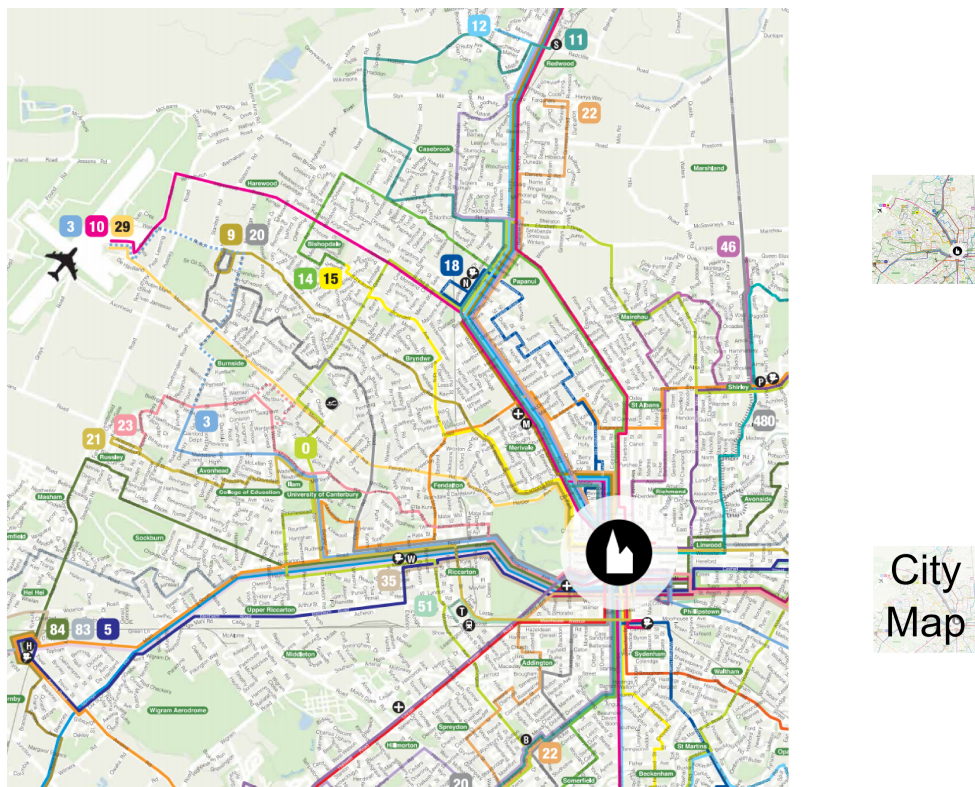


Figure 5.1: (left) The visual angle is large and detailed information can be perceived. (top-right) The visual angle is small and it is harder to gather information about the image. (bottom-right) Text is added at the small visual angle so that information about the image can still be gathered.

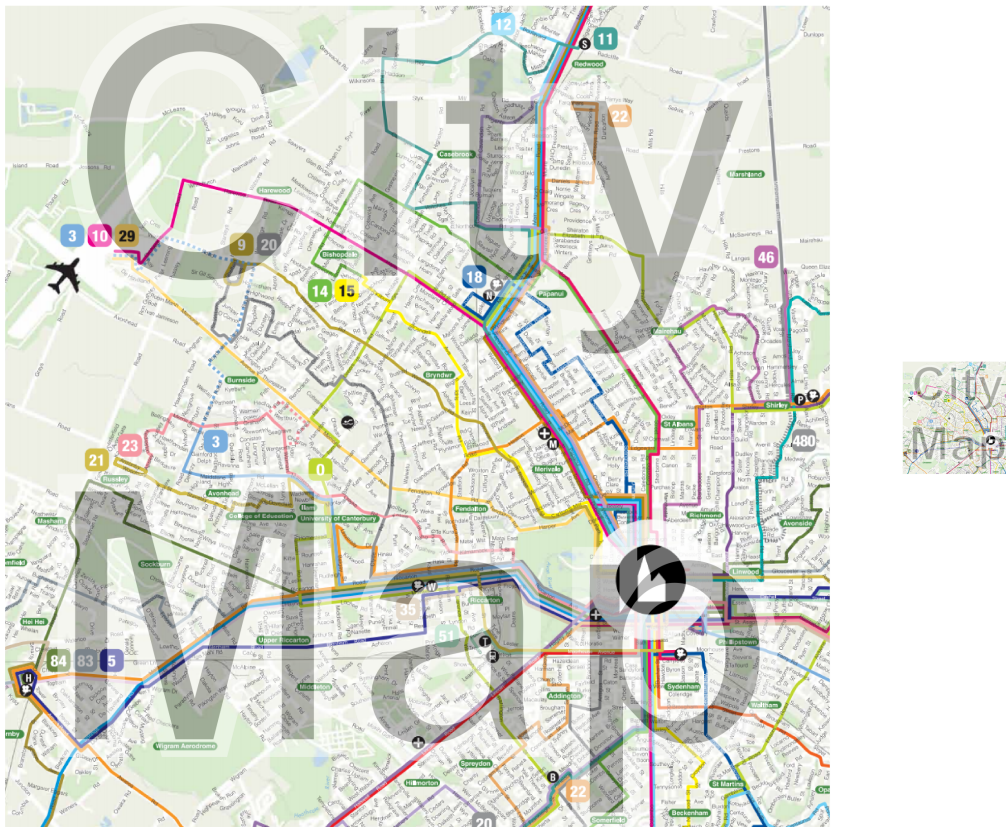


Figure 5.2: (*left*) The visual angle is large and detailed information can be perceived. (*right*) The visual angle is small and information about the image can still be gathered.

it is a raster image or vector image [29]. Raster image detail is anchored to a resolution and can only be displayed at limited sizes on the display without defects in the image becoming visible. On the other hand, vector images are re-rendered to different resolutions when resized and provide a clear image whatever the magnification.

Repositioning Content

The closer an image is positioned next to a user the clearer the view of that image the user will have [63, 50]. If the amount of time a user spends using the display is small, swapping viewer positions could be time consuming relative to the time a user views a display. For example, if a user is watching a display only for a number of minutes before moving on but is still required to change his position to comfortably view content.

You et al. employed user location to dynamically adjust the position of images on a large display in a home [75]. Participants found the crossing of each other's sight-lines when the video feeds did not adjust to user position agitating and/or annoying. Some comments from the participants on crossing other users' sight-lines were 'cannot see (my content) clearly', 'inconvenient', 'difficult', 'irritating' and 'confusing'.

This suggests that the discomfort felt by users when viewing content that is not directly in front of them is more than a result of small visual angle or high perspective distortion. There may also be a social discomfort in looking past someone to view content and reducing this may be another advantage to adjusting a layout to a user's position.

Optimal Visual Angle

Screen space is limited and increasing the size of one image may result in another image being decreased in size. A layout system must divide the screen space among the images. If a user wants to view an image then what size or visual angle should be favoured for that user?

Visual angle affects our ability to recognise objects, to read text and perceive detail [63]. If the visual angle is too small then a person will not be able to perceive enough detail to identify an image. Lindberg and Näsänen [42] found that if icon sizes were displayed below the small visual angle of 0.7 degrees then search times increased significantly.

If the visual angle of an object is large then more detail will be able to be perceived by a user. But the affect that the visual angle of an image, a group of images or the display has on users is more complex and a larger visual angle is not always desirable. Biederman and Cooper [13] performed an experiment to find the optimal visual angle to recognise images and the results suggested 4 to 6 degrees of visual angle (object recognition times were slightly faster within this range).

Gould and Grischkowsky [28] argued that text with large visual angles requires more eye fixations and head movements, resulting in user discomfort and reduced reading speed. Fewer characters will cover the foveal region, the part of the eye necessary for reading and responsible for sharp central vision, and this will increase the number of eye movements required to read all the characters in the text.

An experiment by Gould and Grischkowsky showed that if the visual angle of the width of lines of text is too large it can affect proofreading speed and accuracy [28]. Gould and

Grischkowsky tested proofreading speeds at visual angles of 6.7, 10.6, 16.0, 24.3, 36.4 and 53.4 degrees. Results showed proofreading speed and accuracy to be nearly invariant between 16 and 36.4 degrees, and proofreading to be reduced at 53.4 degrees. Although, the proofreading test used in this experiment may not generalise to reading comprehension.

There is a limited angle a user can rotate their eyes and move their head, and within this limit is the range of motion that is comfortable and can be performed over time without fatigue. Participant feedback in an experiment involving participants using large, projected displays for daily work suggested that the body orientation required to view content affects what content layouts users find desirable [12]. If the visual angle is too large then a user may be required to move their head to take in the whole image, like a viewer sitting in the front row of a cinema.

Lastly, there are the concerns of the designers of content. Designers may favour one visual angle, or a limited range of visual angles. This may be visual angles where the user can comfortably perceive all the information the content provider wants to present and any other visual angle is suboptimal. One specific visual angle may provide the sense of presence that a content provider wants to achieve or may be the proportion of the visual field the content provider wants to have their image cover.

Constraining images or the group of images that a user is interested in to within a visual angle that does not require head or body movements to view all images of interest may increase user comfort. Furthermore, designers could limit the visual angle of content for very close users, as medium range visual angles could aid reading and image recognition times. Yet, the visual angle of images should not be too small for any users as they will not be able to perceive the image, and in general, the visual angle of images should be large as this increases visual acuity.

Fixed Visual Angle

Fixed sized content, no matter the user distance from the screen, could be created if content is sized proportionally to the distance a user is from the screen so that a constant visual angle is maintained. An image would be projected at a consistent size on the user's retina (as was proposed in the E-conic system [50]).

This technique would assign more space to users far from the screen and create similar, more even visual angles among audience members. One disadvantage with this approach is that far users will use more screen space than close users for images with equivalent visual angles, and far users will be more expensive in terms of screen space to maintain. Maintaining this illusion may be difficult with multiple users, as an adjustment in the size of content to accommodate the illusion may not be possible when other parts of the screen are being used by other users.

The benefit of this technique is that a favoured visual angle can be maintained regardless of the user's position. The visual acuity and the detail that will be able to be perceived will be maintained even as a user moves towards and away from the display.

Perspective Correction of Images

Perspective distortion reduces visual acuity by distorting content [50]. However, the perspective distortion of an image can be reduced for a single viewer by transforming the image to a convex quadrilateral, specific to a viewer's perspective, with a linear transformation [50].

Although perspective distortion cannot be removed for more than one viewer, we propose a new technique which reduces it for more than one viewer. Consider the scenario depicted

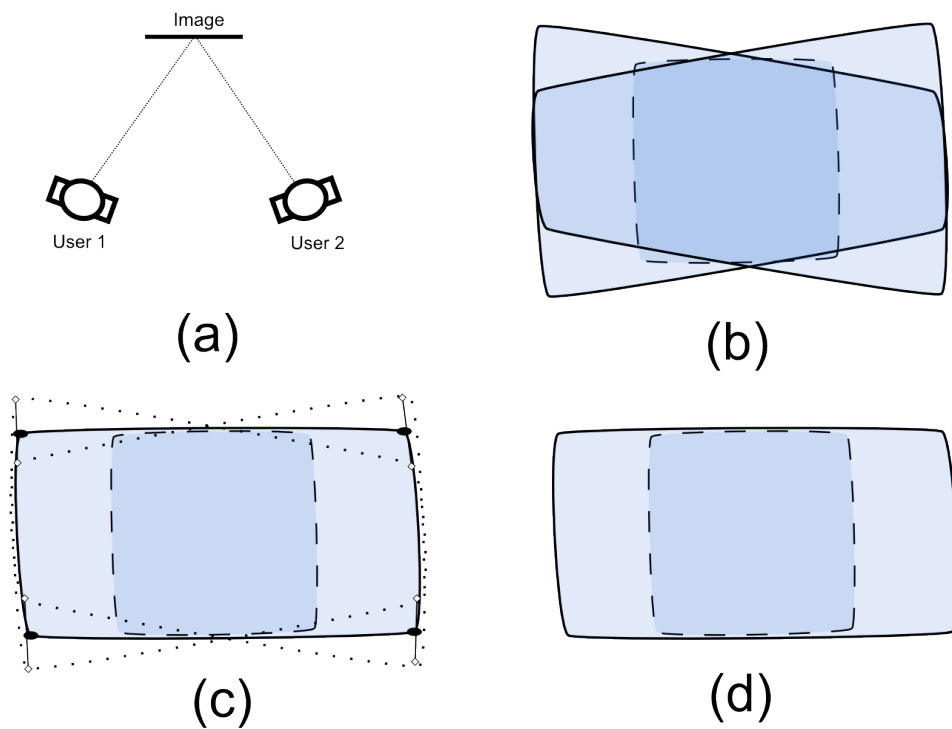


Figure 5.3: (a) Two people view a square image on a display. (b) The two quadrilaterals that would minimise perspective distortion for the two viewers. (c) The linear interpolation of the two quadrilaterals. (d) The resulting rectangular rendering of the image compared to the original square image.

in Figure 5.3, (a). Two users are viewing the same square image, one to the left of the display and the other to the right. The perspective distortion can be removed for only one of the viewers by rendering the square image as either the first quadrilateral or the second quadrilateral (the two quadrilaterals are shown overlapping in Figure 5.3, (b)). A compromise must be made between these two different distortions if the image is to be rendered in a way that is unbiased for both viewers.

The neutral perspective to render the window from would be the average perspective of all the viewers, but this may not produce an optimal outcome. In this example the average perspective would be the front facing perspective. Such a viewpoint would have no perspective correction so the resulting rendering would be a square. But consider the two corrected

quadrilaterals again in Figure 5.3, (b). Both the quadrilaterals have been stretched along the horizontal axis. An alternative method would be to linearly interpolate the matching points in the two optimal quadrilaterals (c). This interpolation would create a rectangle and this rectangle would result in corrected distortion along the horizontal axis for both viewers, unlike the square rendering (d).

However, there are complications with perspective correction. Most images on a computer display, and the display itself, are rectangular. Removing perspective distortion renders a rectangular image as a quadrilateral and this may complicate layout methods designed for rectangular items or consistent shapes (the rendered shape of the image will need to be updated as its viewer's perspective changes). This technique is less effective when there is more than one viewer of an image. LCDs have a reduced image quality when viewed at an angle [71], and perspective correction cannot correct this reduction in the clearness of vision. Lastly, distortion removal is most effective when users are at an angle to the content they are viewing, and if users are commonly viewing images directly then perspective correction will have limited application.

5.2 Handling Multiple Users

The complexity in content layout increases as the number of users increase. There are more viewing positions and user interests to consider. As number of viewing positions and user interests increase so do potential conflicts in interest over the usage of screen space. This section considers factors involved with multiple users and proposes techniques to deal with multiple users.

Users Position and Screen Space

Here we outline how user position indicates the amount of screen space required to achieve a level of visual acuity and how user positions and screen size determine the amount of information that can be perceived on a large display. By defining the relationship between user position and screen space requirements we can help find solutions to allocating screen space on a display with multiple users.

Consider a user viewing a large 5 metre wide screen at a distance of 1 metre. The visual angle would be close to 135 degrees which would allow for a range of content to be placed in that user's visual field. Then consider a user 30 metres from the same screen with a visual angle close to 10 degree. The display would cover as much of the user's visual field as mobile phones screen held at arm's length, and this would restrict the amount of content that could be shown, like the small screen of a mobile phone. We consider users such as the one in this scenario to have high "user cost".

Each user has a cost in terms of screen space that is determined by their position relative to the screen. High-cost users require a lot of screen space to display information. While a low-cost user requires little screen space to display an equivalent amount of information.

There are two variables that can be derived from a user position that affect visual acuity (the clearness of vision). They are visual angle and perspective distortion.

User distance to the screen affects visual angle which in turn affects visual acuity. If a user is far from the screen then that user's visual angle of the screen will be small and if a user is close then that user's visual angle of the screen will be large. To achieve a visual angle of content for a user far from the screen equivalent to a user close to the screen more screen

space is required to render an enlarged image. This is how visual angle indicates the screen space required to achieve a level of visual acuity.

The re-rendering of content to remove perspective distortion also requires additional screen space [50]. Removing perspective distortion increases the bounding box of a rectangle image (the bounding box is the smallest rectangle that encapsulates a polygon). The area of the bounding rectangle increases the greater the angle the viewer is from the centre of the window. While, a viewer angle of zero does not increase the bounding rectangle.

Example Low-cost User A user positioned close to the display and directly in front of the display.

Example High-cost User A user positioned far from the display and at an angle to the display.

The position of users places constraints on the amount of information that can be displayed for viewers. Viewers far from the screen require content to be enlarged if a level of visual acuity is to be achieved. Viewers at an angle to content require additional screen to be used if perspective distortion is to be removed.

User cost in terms of screen space can be measured on a continuum (see Figure 5.4 on the facing page). On one end of the continuum are users positioned close to the display or directly in front of the display that are low cost. On the other end of the continuum are users positioned far from the display or at an angle to the display and are high cost users. This user cost and the finite screen size places constraints on the amount of information that can be displayed to viewers.

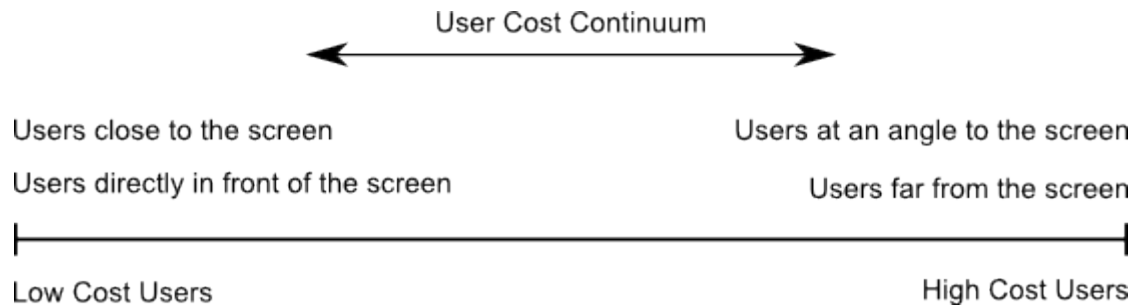


Figure 5.4: User cost in terms of screen space can be measured on a continuum.

Conflicts of Interest between Users

The screen space on a display is limited and conflicting interests between viewers will arise over the use of that space. A conflict of interest may arise between viewers when one viewer favours content to be displayed larger than it currently is and this is not possible without reducing the size of content being viewed by another user. Users may find the system unfavourable to them if content they are viewing becomes reduced in size or is repositioned to accommodate other users. The limited screen space available on a display needs to be managed so that competing interests are resolved. Any solution will involve compromise by some viewers.

Two factors that affect conflicts of interest over space usage:

1. Number of overlapping interests between users
2. The screen cost of users

Number of overlapping interests between users will influence the amount of compromise required by viewers. Shared viewer interest in content will reduce competing interests. While, viewers that have diverging interests will increase competition for space and the greater the amount of users, and the more items on display, the increased chance that interests

will diverge.

Viewer positions will influence the amount of screen space required to achieve a level of visual acuity. A user close to the screen using little screen space would achieve similar visual acuity to a viewer farther from the screen using a large amount of screen space. Unfortunately, the user far from the screen, who uses a greater amount of screen space, is more likely to create a conflict of interest between users.

We are considering automated layouts that do not require human assistance, therefore it is not possible to ask users to resolve conflicts themselves. An algorithm must weigh the various factors and come up with a solution. We categorise automated solutions to this problem into two categories. One category focuses on solutions that favour the individual and the other focuses on solutions that favour the group.

Solutions focusing on individuals ensure that requirements for individuals are met before other areas of layout are considered. For example, this may involve ensuring that for each user there is an image of interest to them that meets a set level of visual acuity so that each user has at least one image that is visible to them. A system that favours the individual may minimise sharing and treat the large display as a display divided up into smaller personal displays.

The next set of solutions focus on the group as a whole. Layouts that benefit the group are given priority over layouts that benefit any one individual. An example solution in this category would be to assign more space to popular content. By assigning more screen space to popular content this would increase utilisation of the screen as the screen's area would be allocated based on the number of people that would utilise that space. This solution would please the group as a whole but images with a minority of interests may not be given a

favourable amount of space.

A system could use both individual and group solutions to resolve conflicts. For example, first images could be positioned and sized so that each user has an image of interest with a level of visual acuity. After this condition had been fulfilled the system could size images based on their popularity.

User Distance and Content Sharing

Users close to the screen have small screen cost, therefore a smaller amount of screen space needs to be used to display content for them to achieve a level of visual acuity. If a user was farther away then their personalised content (content only of interest to them) would monopolise more of the screen and that space would not be available to other users. When considering user costs, content can be personalised for close users more easily than for far users and it is more efficient in terms of screen space to have close users viewing personalised content.

Not only is it more efficient in terms of screen space to have close users viewing personalised content but a user positioning themselves close to the screen could be taken as a sign that they want to view personalised content. A user may be aware that their close position is obscuring other users view and this may be their intent. In human to human interaction a close distance generally means personal information is being exchanged with a friend [39]. Or they may be aware that their high visual angle of content will allow them to view content in a space efficient way which does not monopolise much of the display.

Content Ownership

A system will need to provide feedback to indicate what images the user has selected as being of interest to them but at the same time not obscure images or distract other users with this feedback. Each user could be assigned a colour and the images they have selected could be marked with the colour unique to them. A head shot of the user could be taken with a tracking camera [51] and their face could be shown next to their images of interest. Or a user may be able to determine if a system has detected their interests from the systems behaviour (e.g. repositioning images next to the user) and therefore there would be no need for additional feedback.

Wedge and halo visualisations can be used to show both direction and distance of off-screen locations and have been implemented on hand-held devices (see Figure 5.5) [30]. These visualisations could be ported to large screens to indicate the location of images on a large display that are not viewable from a user's position, to help indicate their location on the display, and appear in front of a user to point to images of interest.

Grouping of Viewers

By organising large audiences into groups the problem of organising content when the viewing audience is large can be simplified. Clusters of people that share an interest in content could be treated by a system as a single entity. Peltonen et al. [58] after observing users of a large, public display with heavy pedestrian traffic found the primary type of interaction to be multi-user interaction and that often a group of users focused on the same image or set of image.

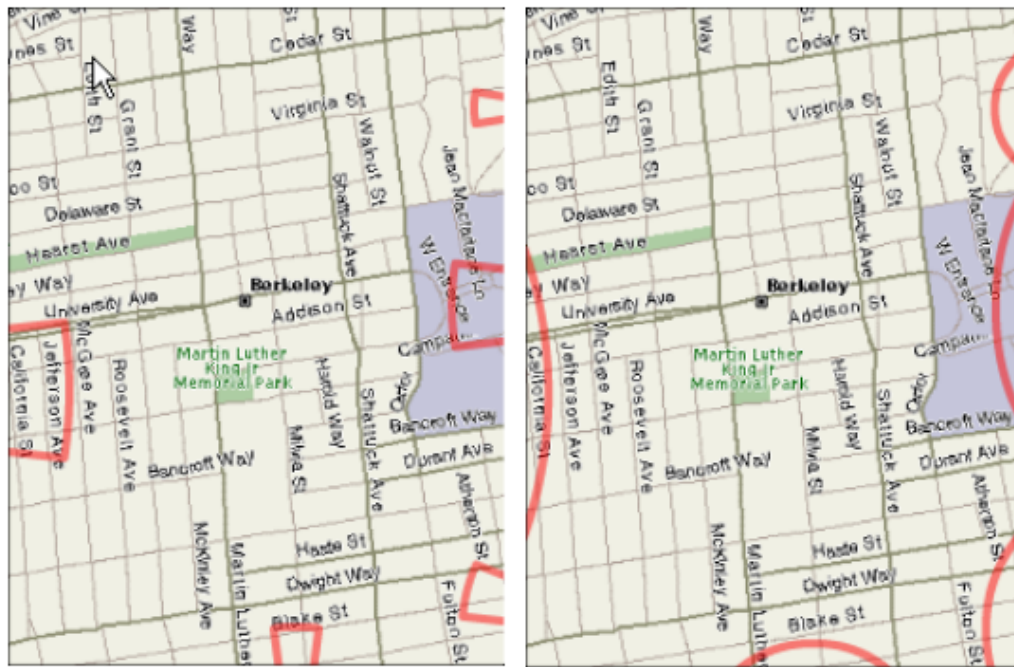


Figure 5.5: Wedges (left) and Halos (right) are used to indicate the direction of and distance to objects off the screen.

Take this example of when audience grouping may be required in a large display system. Five people are viewing the display from the left side of the display and one from the right side of the display. The five people on the left side are close together and all share a similar perspective of the display. A system that would treat each viewer as an autonomous, independent viewer may decide that the display should be optimised for front-left viewing because that is the average viewing point from the viewing angles for the five people. But none of the six viewers would be positioned front-left. If the system could understand that the people on the left side of the screen were a group, it could optimise part of the display just for viewing from that group's perspective and find an alternative for the one person on the right, such as creating a duplicate image for that person to view.

5.3 Layout Transitions

In the two preceding section, we considered what would be favourable sizes and positions for images on a large display to create an image layout. This section deals with how best to transition between layouts and when transitions should occur. We consider what advantages are gained when transitioning layouts and consider potential costs involved in layout transitions.

Responsiveness to Changes in the Audience

Viewers of a large display may be viewing content from changing locations. New users will be approaching the display while other users will lose interest in the display. There are many scenarios of how a display's audience can change and when they do a layout system may consider transitioning the layout and dynamically adjusting to these changes.

However, the amount of change in the layout of content should be balanced with the need to adjust content as a system needs to consider how the movement of content will affect users viewing experience. Users may be agitated if content they are viewing is moved too frequently or unpredictably. Additional, users need to be able to track the movement of content of interest as it moves around the display so that they can locate information after it has been repositioned.

This presents a conflict between responsiveness to changes in the audience and calm, non-distraction updates to the layout. Responsiveness to user input prevents a system from appearing sluggish or slow and allows a user to see the immediate result of their input. But at the same time, on a shared display responsiveness to one user may be distracting to another user

or a quick response may not be possible when parts of the display are being used by other users. The amount of change in the layout of content will need to be balanced with the need to adjust content.

Maglio and Cambell [47] investigated amount of user distraction created by the animation of peripheral content and evaluated different ways of displaying peripheral information. Maglio and Cambell recommended that animated updates be kept to a minimum and, if used, they should not be continuous. They argued that discrete animation is more appropriate than continuous updates and content should be changed with a quick animation and then pause until the next animation. Maglio and Cambell work with peripheral information suggested that it would be best to update a layout with quick animation, and then pause until another update is required, rather than to continuously update the layout, to reduce the amount of distraction updates may cause.

Another perspective on the trade off between calmness and responsiveness is topological consistency [45]. Topological consistency is the idea that changes in layout should be proportional to changes in input. A new layout cannot be calculated without regard to the previous layout. Minor changes in the input (e.g. user locations and interests) should lead to minor changes in the layout. Lüders et al. [45] referred to this as topological consistency, a measure of change from one layout to the next in relation to the change in input.

System Metaphors

Norman [54] argued that it is important for a user to have a mental model of a system as a mental model can increase usability by allowing a user to anticipate how their actions affect the system in novel situations. A metaphor for the movement and layout of content may help

users understand a system's behaviour by relating it to concept that is intuitive or familiar to a user [25]. If a user can understand the mechanics of the concrete metaphor then they can apply that understanding to the layout system.

The metaphors that can be applied to a system's behaviour depends on the algorithm chosen to implement the system. A machine learning algorithm does not lend itself to a simple metaphor as the position and movement of content is determined by a complex algorithm that a user could not comfortably mentally model. An illusion will need to be created for the movement to appear to behave like objects familiar to a user.

On the other hand, force based algorithms model the movement of physical objects. The movement of physical objects can be observed in everyday life. The human mind is practised in predicting the behaviour of velocity, acceleration and pressure on objects. If the movement of images is based on physical forces, content will move, expand and collide in a way familiar to viewers. The system's state will be observable through image's velocity, momentum and position. Viewers can take their knowledge about the physical world and apply it to the system so they can anticipate how their actions will affect the system. Layouts based on these physical behaviours may be easier for a user to mentally model than other algorithms.

The number of metaphors possible for layout systems are large, and the metaphors appropriate will depend on the algorithm implemented or force simulated. If an algorithm simulates the movement of springs then a representation of a spring moving content could be shown to a user. If an algorithm simulates the affects of pressure on objects using Boyle's Law then a metaphor involving gases or liquids may be appropriate. Creativity will be required to find a metaphor that effectively portrays system behaviour while being intuitive and familiar to a user. Our first prototype system used a metaphor to layout content and is discussed in the Chapter 6, "Developed System: VAL".

Animated Image Movement

Animation of the movement and resizing of content is an important addition to layout systems. Layout transitions without fading or smooth resizing may be unappealing, disorientating or distracting. To make for an engaging experience we can aim for the transitions to be aesthetically appealing, allow for focused attention and to be enduring as these are attributes that correlate with engagement [55].

Not only could transition animations be engaging but could also provide utility by allowing a user to track the movement of images around the large display. Adding trails behind the movement of content could help users track the movement of content. The movement of objects can be hard for users to follow on a large screen where objects may move to a location that is outside of a user's visual field. Adding trails to the movement of content on wall sized displays may allow for users to follow the movement of content more easily. Trails have been effective in helping users locate windows on large desktop displays [33].

We can break image movements into categories. First there is resizing and repositioning to an adjacent position. These image transitions allow for smooth interpolation between current and target size and position that do not result in another image being occluded (see Figure 5.6). Second, there are image transitions where the image needs to move to another location. If these transitions are interpolated they may result in other images being occluded (see Figure 5.7).

We designed five transitions that change either the shape, rendering order or opacity of an image as it transitioned to observe which transition through a static image would be aesthetically appealing, allow for focused attention and be enduring for viewers (see Figure 5.8 on page 61). a) Basic interpolation of image position between current position

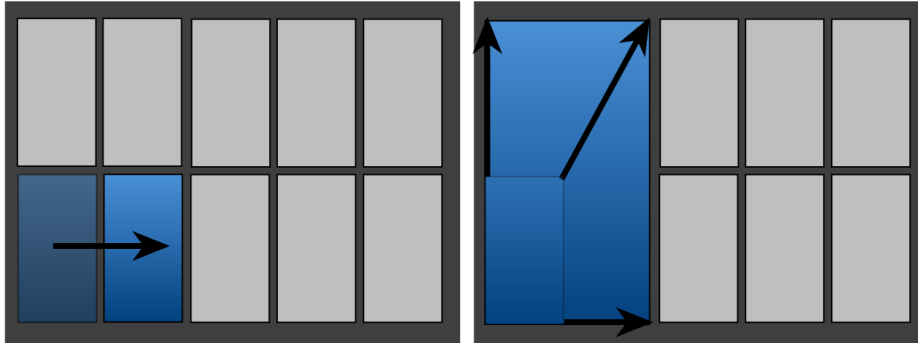


Figure 5.6: Two interpolations that do not occlude other images. (*left*) Image repositioning that does not cross the path of a static image. (*right*) Image resizing, which does not cross the path of a static image.

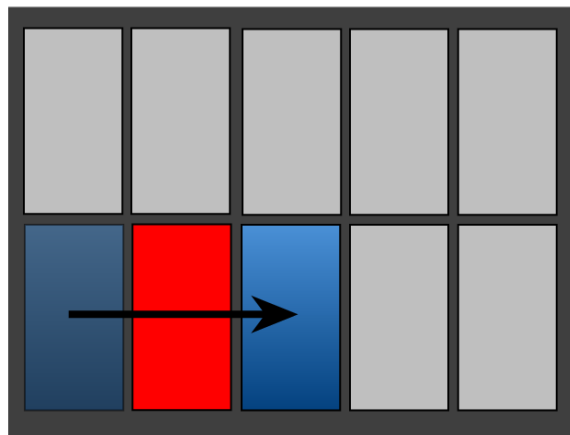


Figure 5.7: Static image (middle shaded rectangle) is in the path of a moving image's interpolation.

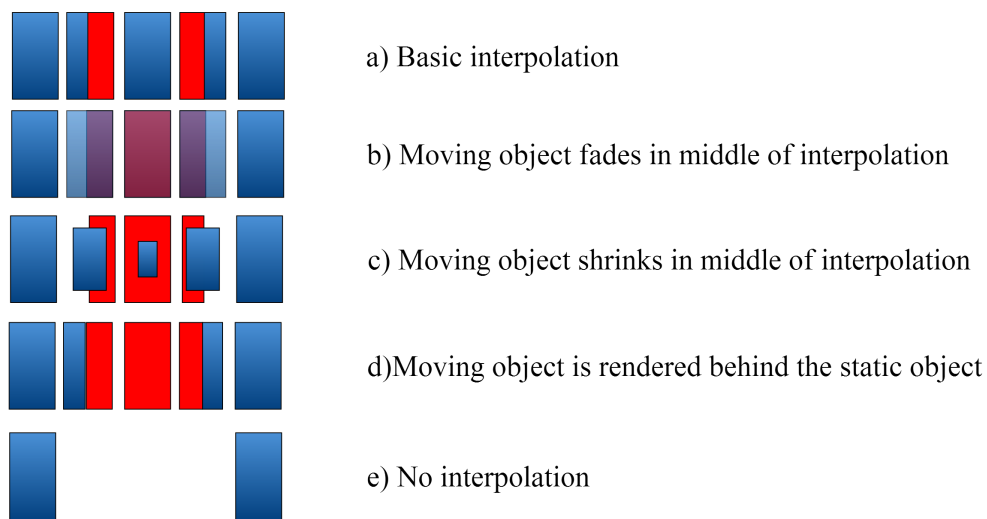


Figure 5.8: Four interpolation transitions that change the shape, rendering order or opacity of an image as it transitions. Each cell in a column shows the transitioning image in blue along with the static image it is passing through in red.

and target position b) Moving image's fade is proportional to its distance from the middle of its interpolation. c) Moving image's size is proportional to its distance from the middle of its interpolation. d) Moving image is rendered behind/after static image. e) No interpolation (the image fades out from its current location and then fades into its target location).

After viewing the effects of these transitions we found the interpolation of an image to be aesthetically appealing yet we found that occlusions of an image being viewed can be distracting, as was the case for transitions (a) to (c). We found the last two transitions (d) and (e) to be the most satisfying because they did not occlude static images. Transition (d) had two additional advantages over (e) of indicating the direction the image was moving to the user and allowed the user to follow the image's movement to its target location.

5.4 Overall Layout

This section covers a number of ways to structure the overall layout of images. We cover structures that can increase the aesthetics of the display, provide flexibility when placing content or give the display consistency and structure.

Aesthetics

O'Brien and Toms [55] found high self reported ratings of aesthetics in software positively influenced the ratings of statements relating to perceived usability, focused attention, felt involvement, and durability. Some large display layouts are created by hand and focus is given to making the layout aesthetically pleasing. When layouts are automated the human guidance is lost. Different layouts may satisfy the needs of users on a large display such as positioning content next to viewers and making good use of available space but not all will be aesthetically pleasing.

One problem with focusing on the aesthetics of the overall layout is that it may not be visible when users are close to the display. There are a couple of factors outside of the control of a layout system that affect the aesthetics of the display. They are the content itself and the viewing position of users. Nonetheless, two things that can be considered when sizing and positioning content are visual balance and the grid method.

Visual Balance Visual balance is a metaphor used in design to describe the effect object size and colour has on the aesthetic appeal of a canvas [44]. Physical objects will balance on a scale when their weights are equal, while an image has balance when the two halves of the image attract the eye equally. Some examples on what is considered to attract the eye in

design and are “heavy” objects [44, 4]:

- Big items appear heavier than small items.
- Areas of high contrast appear heavier than areas of low contrast.
- Colours appear heavier than grey.
- Textured objects appear to be heavier than solid colour objects.
- Areas that are dark appear heavier than areas that are light.
- Warm colours can be seen as taking up more space than cold colours which can be viewed as contracting an area.

Lok et. al. proposed a process where layouts could be mathematically analysed for aesthetic appeal by determining visual balance [44]. This technique could be used on large displays to automate the position of images to create balanced layouts. For example, content that is heavy on one side of the display could be balanced by positioning other heavy content on the other side of the display.

Grid Image sizes could be constrained to a grid to increase the aesthetics of a layout. The symmetry and consistent structure provided by a grid structure is considered in the field of design to be aesthetically pleasing [43]. For example, all images could be placed in a 6 by 2 grid.

Below is an example set of layouts for images on a large display that use a grid structure (Figure 5.9 on the following page). These example grid layouts show symmetry and consistent structure. The screen is divided into an 8 by 4 grid and the screen is of aspect ratio 4:3. The items can be one by one, two by two, three by three, and four by four.

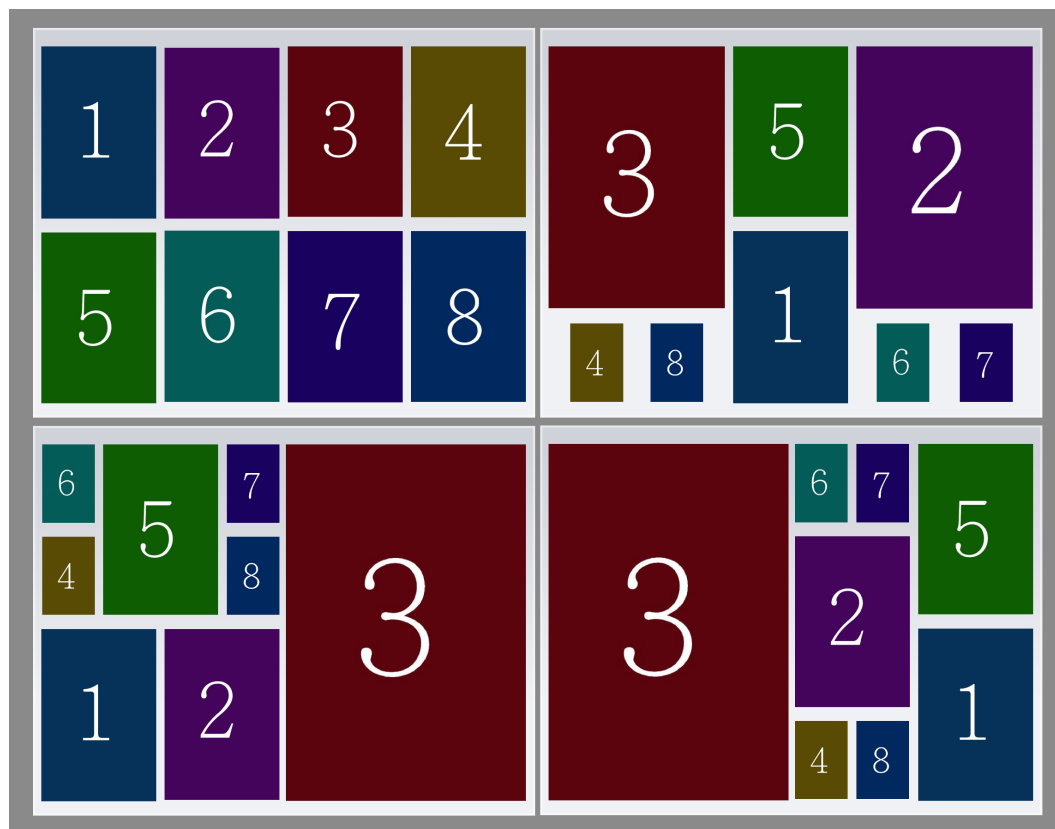


Figure 5.9: An example set of layouts that use a grid (8 by 4) structure and fixed aspect ratio images.



Figure 5.10: On one end of the continuum is a very constrained possible layout set and on the other is a very broad layout set

For greater flexibility the divisions in a display can be increased (for example, moving from 6 by 2 to a 12 by 4 grid or to a 24 by 8). The possible layouts and images sizes increase along a continuum up until the grid defines the pixels of the display. On one end of the continuum is a very constrained set of layouts with consistent structure and on the other is a very broad set of layouts without structure (see Figure 5.10).

White Space White space on an image layout is the unmarked space between images and influences visual balance [44]. White space can not only determine if a layout is aesthetically appealing but also influences how image groups are perceived [60]. Images that have large white space around them will be seen as singular images. Two images beside each other with no white space may not be distinguishable as two images. The amount of white space perceived will depend on the visual angle of the display. White space that may effectively separate two images when users are close to the display may not do the same when users are far from the display (see Figure 5.11 on the following page).

To correct for this change in perceived groupings of images a system could increase the white space between images when there are users viewing the display from a distance and adaptively change the white space depending on user distances. This will allocate white space when needed and will otherwise maintain space for image. A simpler, but less efficient, approach would be to ensure the white space between images is large enough for users at a range of distances.



Figure 5.11: White space separates two images when the visual angle is large (*left*) but does so less effectively when the visual angle is small (*top-right*). More white space may need to be added when the visual angle is small to separate images (*bottom-right*).

Distortion Methods

Another technique that can be applied to the layout as a whole are distortion techniques. Distortion techniques allow a layout to be spatially distorted to increase the space used by the items of interest to users while still retaining visibility of other items. Example distortion techniques are fish eye [61] and perspective wall [46] (see Figure 5.12 on the next page). Fish eye expands an area of interest in a sphere shape. The middle is expanded to increase visibility of items in the middle and the surrounding regions are reduced in size. Perspective wall expands a vertical middle strip of the screen and distorts the adjacent two side regions.

Distortion techniques could be used to increase the visibility of images of interest to users on a large display and decrease the space used by other images. Fish eye and perspective wall increase the size of images that are all located in the same place and located in the middle of the display, but these distortions could be expanded upon, or other distortion created, to allow for images to be increases in visibility in locations other than the middle and increased in visibility in multiple locations (see Figure 5.13 on the facing page for an example) similar to distortions used in visualisations [62].

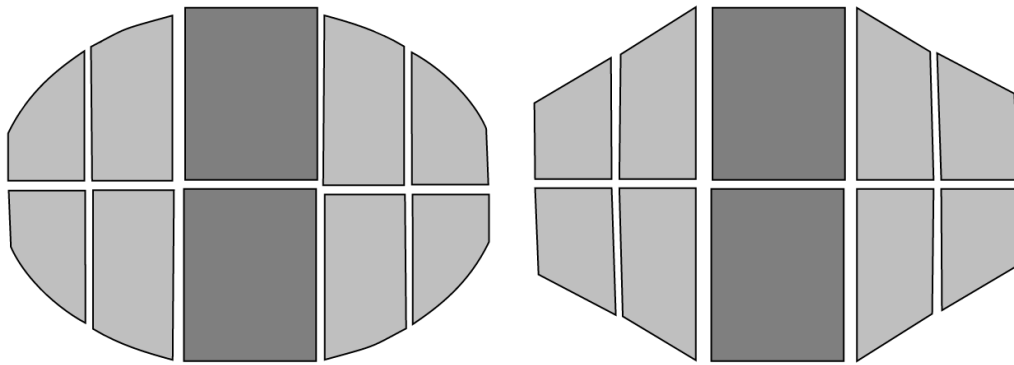


Figure 5.12: Fish eye distortion (left). Perspective wall distortion (right).

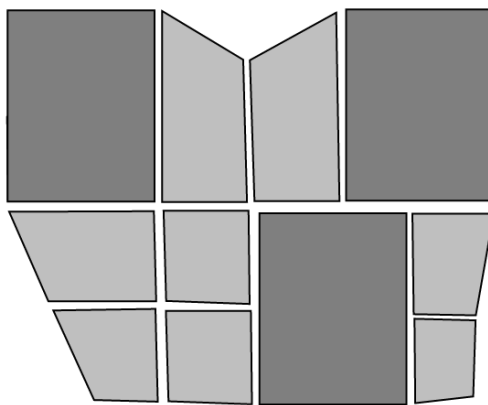


Figure 5.13: A distortion technique that allows for images of interest in multiple locations and in locations other than the middle of the display.

Distortion techniques allow the resizing of fixed aspect ratio images to fit spaces with other aspect ratios. Many images and photos have fixed aspect ratios. This fixed aspect ratio reduces the flexibility available when sizing items on a display. Distortion techniques provide a way to fill the available space by allowing content to be reshaped. For example, there may be a free rectangular space available on the display but the content needing to be placed is square. The square image could be squashed and distorted along one axis to fit into a rectangular space or a 3D transformation could be applied that would transform the geometry into the rectangular space as a quadrilateral. The distortion would allow the content to fit a new shape while retaining its visibility.

The addition of shading to distorted geometry helps produce a more complete 3D effect. Changes in luminance over a two dimensional image are used by the human visual processing to guess the 3D geometry of an object [19]. It is recommend by Carpendale et. al [19] that distortions be illuminated by a single light source as the human visual system assumes a single lights source coming from above. While shading increases the ability of users to process 3D illusions, it may obscure images by increasing or decreasing the luminance of areas an image. Carpendale et al. discusses techniques to make distortions of images comprehensible.

5.5 Conclusion

This chapter presented design factors and considerations for layouts and layout transitions. Section one considered ways to adapt content to user position including reposition and resize images. Section two looked at the factors involved in managing multiple users on a large display. We first defined “user cost” a measure of the screen space required to accommodate a user at a specific position relative to the screen. We looked at factors that would influence the

amount of conflicts in interest over the usage of screen space and categorised the automated ways to resolve conflicts. We looked at the relationship between user distance from the screen and the amount of shared viewing of content. We explored ways to indicate to user what content they have expressed interest in. Section three considered layout transitions and proposed five ways to transition images across the screen with the aim of allowing focused attention and for users to follow the movement of images. Section four reviewed three ways to manage the layout of images as a whole. We considered using the metaphor of visual balance and the grid method to enhance aesthetics on a large display layout. Lastly, distortion methods are considered which expand and highlight images of interest by distorting the layout.

6 Developed System: VAL

First our prototype system is described and two difficulties observed with the prototype system are outlined. Next, VAL is introduced and the techniques applied to the VAL system are covered. Lastly, the architecture of VAL is covered in three subsections, static objective function, dynamic objective function and measurements.

6.1 First system

Our first, prototype system controlled layout with a force based algorithm involving both Boyle's Law and Newtonian Physics. We hoped the metaphor and simulation would increase understanding of the system and produce a novel system. Images were represented as items that reacted to physical forces in a simulation. When users expressed interest in an image, a force was applied to the image which pulled the image towards the user. Images would react to forces by pushing together, pulling apart, colliding, expanding and shrinking. These reactions were repeated iteratively, many possible layouts being tested, until the system came to an equilibrium state where images paused as all forces were in balance.

We could model a number of principles that adapted content to the audience using this simulation. Images could be positioned close to users that express interest in them with a force that pulled images towards users. Images expanded at a rate proportional to their popularity so images made use of available screen space with the popular images dominating the display. We aimed for a rate of expansion that would produce a system responsive to changing image popularities yet a rate where object movement would still be smooth and easy to follow.

Images distorted themselves to the perspectives of the users that expressed interest in them, rendering them as quadrilateral and reducing perspective distortion. The force based layout provided a way to find layouts even when the image shapes were quadrilateral by allowing images to press up against each other and slide into available spaces (see Figure 6.1).

From this prototype, we observed two problems with our design. The first difficult we had with the prototype system was that some system features could not be simulated in a way that would be consistent with the rest of the system's behaviour. Controlling the movement of images using only physical force simulation was limiting, and the simulation and metaphor had to be stretched to accommodate system features. For example, we wanted to have items reposition themselves close to users that were interested in them. To begin with, images would aggressively move to the other side of the display by pressing through the other images and pushing them out of the way. This behaviour was quite distracting so we adjusted the system behaviour to have images slide past each other and break the simulation of Newtonian physics by teleporting items to locations. But initial user feedback revealed this behaviour to be unexpected and the simulated to confuse users rather than help users to understand the system's behaviour, especially when the simulation was not consistent.

The second difficulty was with the technique used to remove the perspective distortion of content. Its utility was minimised by the fact that content was repositioned next to users where there was close to no perspective distortion. The reshaping of images also degraded the visual appearance of the layout by transforming rectangular images to quadrilaterals. This transformation took away the symmetry of the images which reduced the visual balance of the previously symmetrical rectangular images (see Figure 6.1). Chang et. al [22] described the loss in visual balance when objects are not symmetrical in the following way, "A visual object will appear as incomplete if the visual object is not balanced or symmetrical. A psychological sense of equilibrium, or balance, is usually achieved when visual 'weight' is



Figure 6.1: First, prototype system simulated Newtonian physics to produce layouts and included perspective correction of images.

placed evenly on each side of an axis.” Because of these difficulties the VAL system design was favoured instead.

6.2 VAL

VAL is an automated layout for large, shared displays which can be used to present a collection of images. VAL utilises user position and expressed interests in content as input to generate and update an image layout. We created a set of movie posters to present on VAL.

It was our goal to design an engaging system that would first attract users to view images by being aesthetically pleasing and novel and a system that once it has attracted users to view

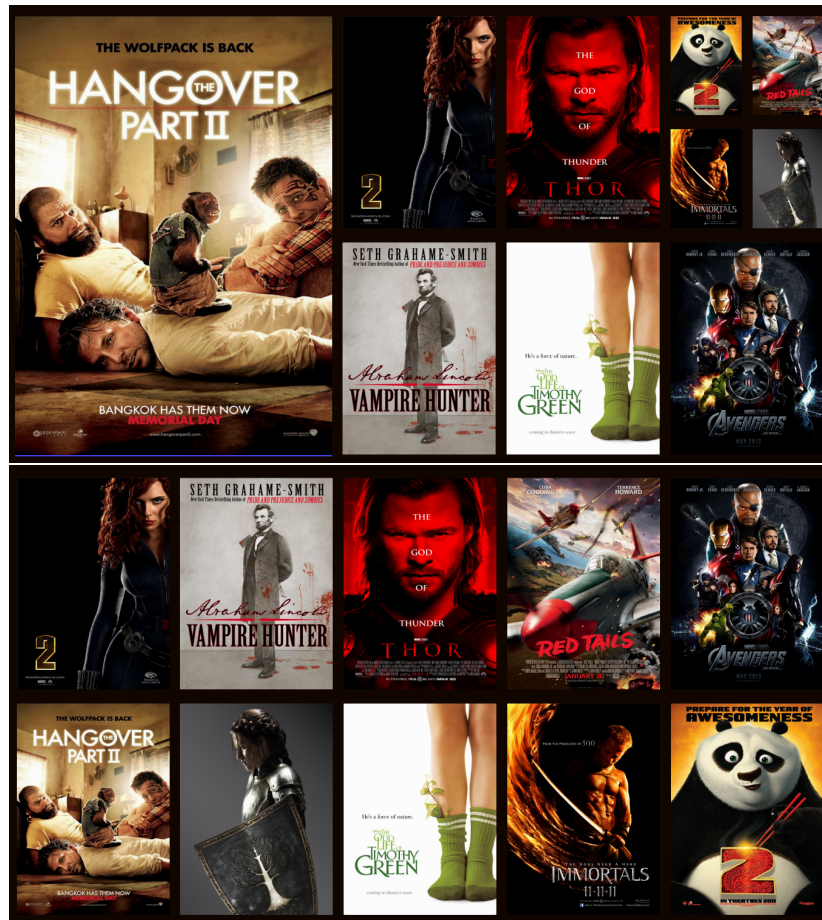


Figure 6.2: Two example layouts that use VAL's grid structure

and interact with the system would additionally be usable, involving and allow for focused attention. To achieve these goals we made use of a grid structure, content adaptation to visual angle, dynamic and static objective functions, visual balance, and measurements of visual angles and perspective distortions.

A grid structure was chosen for VAL's layout. A grid structure provided good aesthetic properties with its symmetry, consistency, and visual balance (see Figure 6.2). We favoured the grid structure over distorted layouts (see Figure 5.13) and force based layouts because these layouts did not have these aesthetic properties. Images spanned a whole number of spaces. The smallest an image could be was one space. Our images needed to maintain their pixel aspect ratios, of 1:1.5, so the possible grid dimensions for an image were 1x1, 2x2,

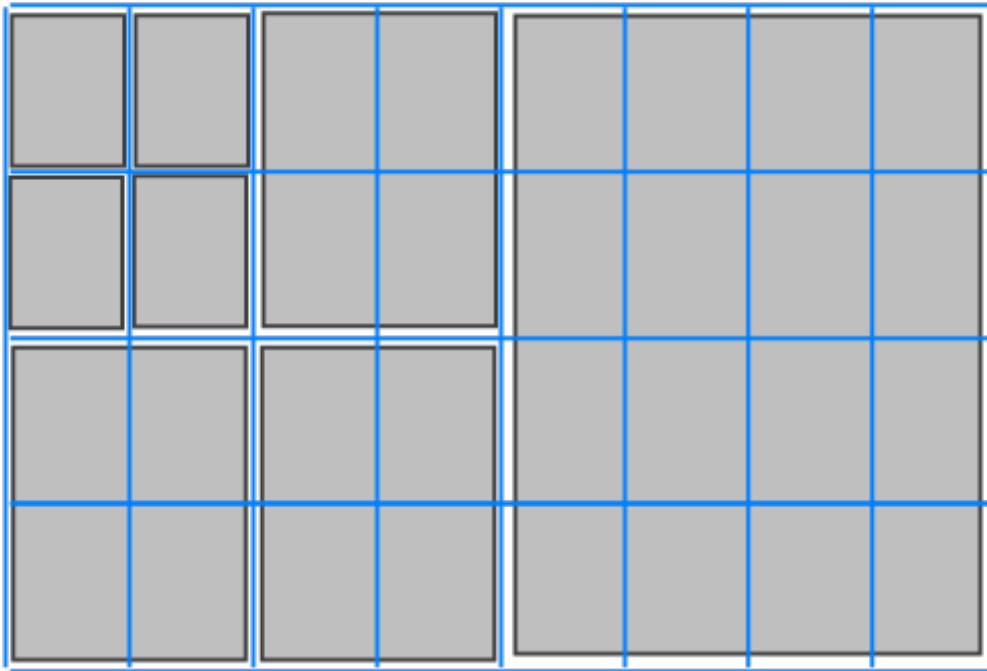


Figure 6.3: Example layout that fits into the 8 by 4 space grid used in the VAL system.

3x3, etc. Our grid size was 8 spaces wide, 4 spaces high and displayed 8 images with 1:1 grid space aspect ratios (see Figure 6.3).

To interact with VAL a user can express their interest in a movie poster by saying “show” and then a movie title or a distinguishing part of a title to the system. The system can recognise this as an expression of interest and then adapt the layout and content with the knowledge of that user’s interest. Expressing interest in a new movie poster or posters replaces a user’s previous interests in posters. User can express interest in multiple movie posters by listing them together in one command, for example “Show ‘Wizard of Oz’, ‘Iron Man’ and ‘Thor’”. By adding “show” before a command we could reduce confusion between a user’s dialogue and commands to the system. All movie posters had unique names so if a user said part of a movie name or a shortened form of a movie name then their interest in the movie would be inputted in the system. Using voice commands allows a user to interact with the system



Figure 6.4: VAL used three images for three ranges of visual angles

without holding equipment such as a pointing device. This fulfilled our goal of creating a light weight interaction technique which did not require a lot of user training or complex equipment.

The images used in VAL adapt to three ranges of visual angles. When the visual angle is small (below 8 degrees) a movie poster is displayed, when the visual angle is median (8 to 16 degrees) the movie poster along with screen shots and a screening times is shown, and at the highest visual angle (above 16 degrees) a movie blurb and actor photos are added to the image (Figure 6.4). This provides utility in that when more detail can be perceived by the viewer then more detail is displayed.

VAL uses a layout technique that can be applied to any collection of images so that it fulfilled our goal of being content agnostic. The placement of images is dependent on user position and user interest and independent of image properties.

VAL uses an objective function to determine layouts and layout transitions and with this aims to achieve two goals. First, to use its objective function to increase engagement by favouring high visual acuity so as to produce an experience similar to watching a large TV or a movie at the cinema. Second, use a dynamic objective function to minimise distraction and help maintain focused attention.

VAL uses the algorithm and technique developed by Lüders et al. [45] for display layout. VAL finds a layout through the optimisation of two objective functions, a static objective function and a dynamic objective. VAL's static objective function aims to maximise visual acuity for users and considers both the visual angle and perspective distortion of images for each user. VAL's dynamic objective function is modelled on the dynamic objective function used by Lüders et al. and considers the amount of change between a previous layout and a proposed layout. Images rendered after/behind other images as they transitioned so as not to distract viewers of the static images (see Section 5.3 "Animated Image Movement" on page 59).

6.3 Static objective function

VAL aims to produce high visual acuity by maximising the sum of the visual angle of each image of interest to each user, minimising the sum of the perspective distortion of each image of interest to each user and maximising coverage of the display. Both visual angle and perspective distortion measure the clearness of content in user's vision and the objective function aims to maximise the visibility of content for users. VAL also favours layouts that make use all available space so the display is perceived to be visually balanced.

Display space is limited and, on a shared display, space must be divided up and then tailored

to multiple users' needs. A static objective function is used to resolve conflicts of interest over display space by weighing the underlining variables that affect human perception to allocate display space. VAL focuses both on the individual and the group. VAL favours increasing the visual acuity of the users with the lowest visual acuity first (low visual angle and high perspective distortion) and then gives priority to the viewer with the next lowest visual acuity and so on until the viewer with the highest visual acuity. Yet the viewer with the best visual acuity is still considered in the calculations so if a layout increase the visual acuity for the viewer with the best view and does not affect the visual acuity of other users then that layout will be favoured.

6.4 Dynamic objective function

The dynamic objective function measures the sum of the difference in size and position of images between the current layout to a proposed layout. This function adds a cost to moving and resizing images. If the benefit in moving content is greater than the assigned cost, the layout can transition. Since this method adds a cost to large movements it tends to result in more stable layouts. With the dynamic object function, we aim to produce a layout that is reactive to an audience's changing needs yet provides an engaging user experience by favouring layouts that only make incremental change.

This final objective function results in a system that maximises the visibility of images of interest for each user while at the same time only transitioning layouts when the benefits in a layout transition outweigh the estimated distraction created.

Final objective function = static objective function + dynamic objective function

The optimisation problem we have defined so far has a large solution space which makes finding a global solution potential computationally intensive. VAL's grid restricts the possible solutions and this reduces the solution space VAL's optimisation algorithm needed to search. To search for a solution, VAL generates random solutions and then picks the one with the highest objective function. To generate each random solution, first a random set of item sizes are generated that could possibly fit inside the grid. Second, the items are positioned closest to users of interest. Third, random movements and resizes are performed on the items until there is no space to perform any more operations. After observing the output of the algorithm we concluded that the random search found a solution to the objective function in a time which provided a responsive system so no other optimisations were performed.

6.5 Measurements

This section defines how VAL measures layout coverage, user visual angle, and user perspective distortion. These three measurements are used in VAL's static objective function. These measurements each assume user positions and a list of items of interests for each user are known.

Each user has the following properties:

- **head position** (This is used to tell the system the perspective of the user. From this input we can determine the visual angle and perspective distortion of content.)
- **content of interest** (This is a set of content that the user has expressed interest.)

Coverage

This formula calculates the difference between the screen area and the sum of each item area.

$$A - \sum_{i=1}^n a_i$$

n is the number of items

a is one of **n** item areas

A is the area of screen

Coverage is percentage of the screen used. This formula assumes that there are no overlapping items. We added the coverage metric because when seen as a whole, layouts that used most of the display looked to have better visual balance.

Calculation of visual angle

This formula calculates the sum of the visual angles of each user's items of interest

$$\sum_{j=1}^n 2 * \arctan \frac{s_j}{2 * d_j}$$

s is the size of one of **n** items and **d** is the distance to one of **n** items.

The visual angle metric takes into account user distance and describes the coverage of the screen in a way that directly measures the affect on human perception.

Calculation of perspective distortion

For each user's items of interest, the angle between the user and the screen are found. This is done by calculating the angle between each vector starting at the user and ending at each image of interest to that user and the normal vector of the screen (see Figure 2.4).

$$\sum_{j=1}^n \arccos \frac{\vec{v}_j \cdot \vec{b}_j}{|\vec{v}_j| |\vec{b}_j|}$$

\vec{b} is the vector with origin at the centre of one of n items and direction equal to the normal vector of the screen

\vec{v} is the vector starting at a user's head and ending at one of n items of interest

$$\vec{b} \in \mathbb{R}^3, \vec{v} \in \mathbb{R}^3$$

Perspective distortion is measured using the angle between the viewer and the image as this angle is proportional to the amount of distortion in an image. Our function is a approximation of the affect viewing angle has on a user's visual acuity.

6.6 Conclusion

VAL is a system that defines layout as an optimisation problem. This chapter covers the layout techniques used in VAL and the system architecture of VAL. VAL makes use of a grid structure, content adaptation to visual angle, an objective function to generate layouts and layout transitions.

Figure 7.1: A projector was used to create a display of size 4.85 by 2.89 metres

7 Evaluation

We ran an evaluation to test whether our system had achieved our design goal of creating an engaging user experience, to measure participant preference for each component of VAL and get feedback about the system from participants experience in using it. The VAL system is made up of two components, content adaptation to visual angle and dynamic layout, and in our evaluation we tested four conditions covering the possible combinations of these components. After each condition participants completed a questionnaire measuring engagement and after the experiment rated the conditions from one to four in order of preference.

7.1 Participants

Eight male participants between the ages 20 to 28 were recruited from the local university and were each given a \$10 voucher for participating. All participants reported having normal or corrected-to-normal vision.

7.2 Apparatus

A projector was used to create a display of size 4.85 by 3.64 metres in a class room. The resolution of the display was 1600 by 1200 pixels. The lights were dimmed so that the projected display was more visible yet there was still enough light so that users could comfortably see the floor and their surroundings. We maintain a consistent light level throughout

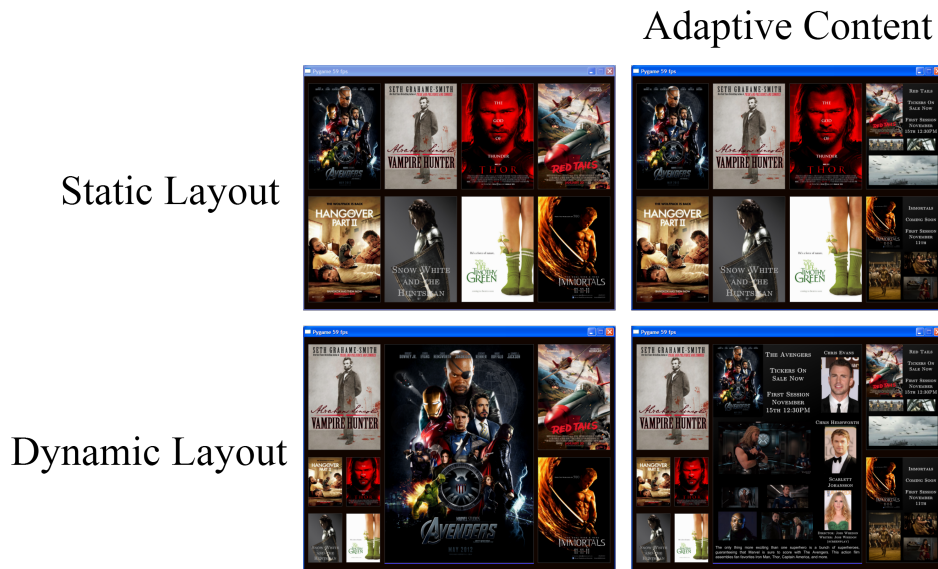


Figure 7.2: Four conditions in the evaluation of VAL.

the experiment by blinding the room’s windows.

7.3 Method

We conducted a within subjects user study with subjects all participating in four conditions (see Figure 7.2). In the static condition (labelled “S”), the display showed an array of movie posters *static* and laid out in a grid with the content not being adaptive to the user’s visual angle. In the dynamic (labelled “D”), the movie posters *dynamically* reacted to the participant’s position and interests, as described in Chapter 6 on page 70, with the content not being adaptive to the user’s visual angle. In the adaptive, static condition (labelled “AS”), the display showed an array of movie posters *static* and laid out in a grid with the content being *adaptive* to the user’s visual angle. In the adaptive, dynamic condition (labelled “AD”), the movie posters *dynamically* reacted to the participant’s position and interests with the content being *adaptive* to the user’s visual angle, as is VAL’s default operational mode.

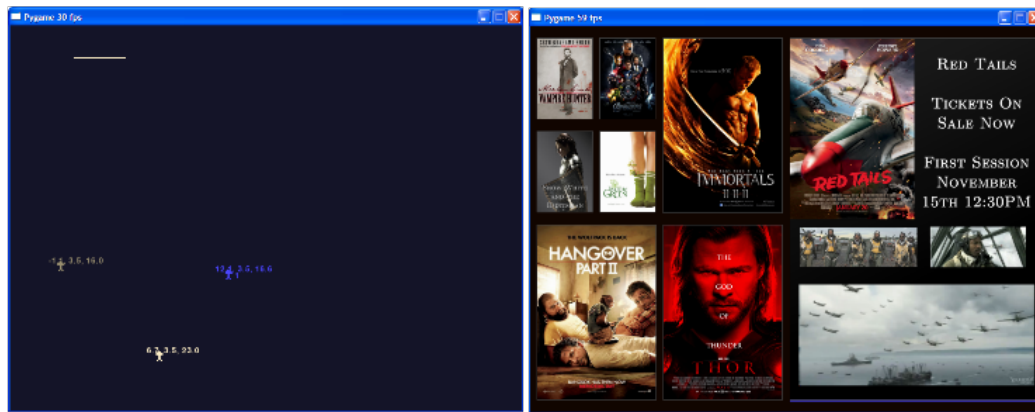


Figure 7.3: When VAL was running a researcher inputted user positions by clicking a point on a window. The beige line indicated the size and position of the display. The three symbols represent users and the x, y, and z coordinates were displayed above the user symbols (*left*). The resulting layout (*right*)

We wanted to simulate the user actions that would have likely occurred in front of a large public display with frequent pedestrian traffic. We had the participants approach the display from a distance as they would if they were walking up to the display in a public setting by having participants begin at the other side of the lecture room (about 20 meters from the display) and then walk towards the display and start interacting with it as they choose. Having the users approach the display from a distance allowed us to test the content adoption to visual angle. Participants approached the display from a distance in all condition to control for factors that would influence the user experience. Participants interacted with the system for 2 minutes in each condition, as it is common for users of public display systems to only interact with them for a short time space [34, 17].

The participants were told before the experiment that a researcher would manually be inputting their position and their interests. Our system did not have the ability to track user positions so this input was simulated. The layout system ran on a laptop connected to the projector. When VAL was running a researcher inputted user positions by clicking a point on a window that had markers for references, such as the display and seats, so that the research could better estimate the user positions (see Figure 7.3). This allowed us to test a layout system

that has the capacity to track users without building such a system.

Our system also could not detect user interests. Participants were instructed to say “show” followed by the name of the movie poster they were interested in and then a researcher inputted the information in the system. Only once a distinguishing part of a movie title was spoken would it be inputted in the system so that researchers would not interpret or assume intentions of participants and computer voice recognition that could not understand ambiguous commands could be more accurately simulated. If participants were confused about how to give a command then they could ask for help from a researcher. When a user expresses interest in a poster by saying its title then a researcher would quickly press a key that corresponded to the movie poster.

Participants were given a survey after each condition to evaluate their engagement while using the system. O’Brien and Toms [55] developed a multidimensional scale to test engagement in software applications. We adapted nine items that were the most relevant to large display layout from the 32 item test developed by O’Brien and Toms to assess engagement (see Table 3 on the next page). Each question was reworded to relate to large display layout and allowed for a response on a five-level Likert scale (strongly disagree, disagree, neutral, agree, strongly agree). The same questions were given to participants to complete after each condition. Participants were asked to write any comments that they had about an interface after using it. At the end of the experiment participants rated the four conditions from 1 (most preferred) to 4 (least preferred).

Item	Non-adaptive content Static layout (S)	Non-adaptive content Dynamic layout (D)	Adaptive content Static layout (AS)	Adaptive content Dynamic layout (AD)
Q1 I was so involved in viewing the display that I ignored everything around me. *	2.5 (1.2)	3.9 (1.1)	3.3 (1.4)	4.1 (0.8)
Q2 I was absorbed in viewing the display. *	3 (1.1)	4.1 (1.0)	3.5 (1.3)	4.3 (0.7)
Q3 I felt in control of my viewing experience. *	2.5 (1.7)	4.1 (0.6)	3.4 (0.9)	4.3 (0.5)
Q4 I could not do some of the things I needed to do while viewing the display.	3.1 (1.6)	2.6 (1.4)	2.4 (1.5)	2.4 (1.2)
Q5 The image layouts were visually pleasing.	2.9 (1.0)	3.5 (0.5)	3.6 (0.5)	4 (0.9)
Q6 Viewing this display was worthwhile. *	3 (0.8)	4.1 (0.8)	3.6 (0.9)	4.4 (0.5)
Q7 I continued to view the images on the display out of curiosity.	3.3 (1.3)	3.9 (0.6)	3.8 (1.0)	4.1 (0.4)
Q8 I was really drawn into viewing the display.	3 (1.7)	4 (1.1)	3.6 (1.1)	4.4 (0.7)
Q9 This viewing experience was fun. *	2.6 (1.1)	4 (0.5)	3.5 (0.8)	4.1 (0.6)

Table 3: Mean (and s.d.) of responses to engagement questionnaire. *=significant difference between interfaces (Friedman Test, $p < .05$).

7.4 Results

Table 3 on the preceding page shows the average responses in each condition for the 9 questions. Preferences for the interfaces differed significantly ($X^2 = 12$, $P < 0.01$) with 0 preferring S, 0 preferring D, 2 preferring AS, and 6 preferring AD.

Five out of nine of the questions resulted in significant differences between responses over the four interfaces. There was a significant difference in reported involvement (**Q1**) between the layouts. In the two dynamic layouts, D and AD, the means were 3.9 and 4.1 respectively and in the two static layouts, S and AS, the means were 2.5 and 3.3 respectively. This indicates that either of the two components of VAL, the adaptive content or the dynamic layout, increases involvement. There was a significant difference in reported adsorption in viewing the display (**Q2**) between the layouts. The mean in the two dynamic layouts, D and AD, with the means being 4.1 and 4.3 respectively and in the two static layouts, S and AS, the means being 3 and 3.5 respectively. There was a significant difference in felt control of viewing experience (**Q3**). The mean in the two dynamic layouts, D and AD, with the means being 4.1 and 4.3 respectively and in the two static layouts, S and AS, the means were 2.5 and 3.4 respectively. In the dynamic layouts the user could express interest in images and the layout would be tailored to their interests. There was a significant difference in report fun of the viewing experience (**Q9**). The mean in the two dynamic layouts, D and AD, with the means being 4 and 4.1 respectively and in the two static layouts, S and AS, the means were 2.6 and 3.5 respectively.

7.5 Discussion

There was no significant difference between the answers to (Q4), “I could not do some of the things I needed to do while viewing the display.” No difference was detected in the results even though in three of the conditions the system utilised content adaptation and dynamic layout. These two techniques may not have affect users’ ability to perform tasks significantly. No significant difference was reported between the aesthetics (Q5) of the layouts in the four conditions. We failed to detect a difference even though in two of the conditions (S and AS) the posters were evenly arranged by hand in a balanced, symmetrical pattern and in two of the conditions (D and AD) the posters were dynamically generated in many different grid layouts by an algorithm.

Some user comments supported the idea that VAL’s automated layout and content adaptation can increase user engagement. One user’s commented that any layout change would have made a display more interesting “When viewing the poster images I felt that if the images would randomly move the user experience would be more interesting or the user would be more drawn to the posters.” Another participant’s comment in the static layout condition suggested that layout changes specific to user interest would provide utility “I was not able to control the interested columns fully. I was more interested in one particular item more than the other one.”

One participant commented that when the detail in the posters did not adjust to their distance that “[the posters were] very hard to read from far away”. The detail in the posters changed when the participant’s visual angle to content changed. At what visual angles the posters changed was not known to participants and many participants would not have been familiar with the concept of visual angle. The lack of understanding of and control over when the detail in the posters changed confused one user and their comment was “Unsure of the

distance required. What did I need to do to get a response?” Feedback about when the detail in the posters would change could reduce users’ confusion while using VAL. Automating a tasks may result in reduced understanding and felt control over a system compared to a manual layout. There are techniques that could be used to potentially increase understanding of an automated system to a user such as metaphors.

In questions relating to engagement the responses were significant higher in five of the nine questions in the conditions involving a component of VAL. When some or all of the components of VAL were added to a layout users agreed more strongly with statements describing their experience as engaging.

8 Conclusion and Further Work

Many researchers have applied automated layouts to items on a graph, content on a document or windows on a desktop but only a subset of common layout algorithms have been applied to large displays and the quantity and scope of research in large display layout is smaller in comparison to other domains. We proposed six goals for automated, large display layouts and explored the display space for layouts. We explored design factors and considerations for layouts and layout transitions, including image reposition and resize, managing multiple users on a large display, layout transitions and layout aesthetics. We presented VAL, a layout system that defines layout as an optimisation problem, and reported that there is a significant increase in agreement by users with statements describing an engaging experience when VAL is applied to an image layout.

Our layout designs and the VAL system both focused on assigning display space for images so they could be seen by all interested users. In future work, the application of these techniques could be used to assign display space to media other than images such as video or interactive media.

We observed users interacting with two layout algorithms, force based and VAL's machine learning algorithm. Researchers could apply treemaps, additional force based algorithms or other variations of automated layout algorithms to large displays.

Our design focused on the user and their needs for an automated layout. Another approach could be taken in the application of automated layouts for large displays with focus been given to the needs of providers of content such as advertisers. The goals and incentives of advertisers may differ from pedestrians and the design of layouts could be augmented to support advertisers' goals. Advertisers may only require a short amount of a user's time

to project their message and aggressively drawing user's attention to the display may be a priority.

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